METALLURGIA

The British Journal of Metals

(Incorporating The Metallurgical Engineer)

Readers are invited to submit articles for publication in the editorial pages; photographs and/or drawings suitable for reproduction are especially welcome. Contributions are paid for at the usual rates. We accept no responsibility in connection with submitted manuscript. All editorial communications should be addressed to The Editor, "Metallurgia," 31, King Street West, Manchester, 3.

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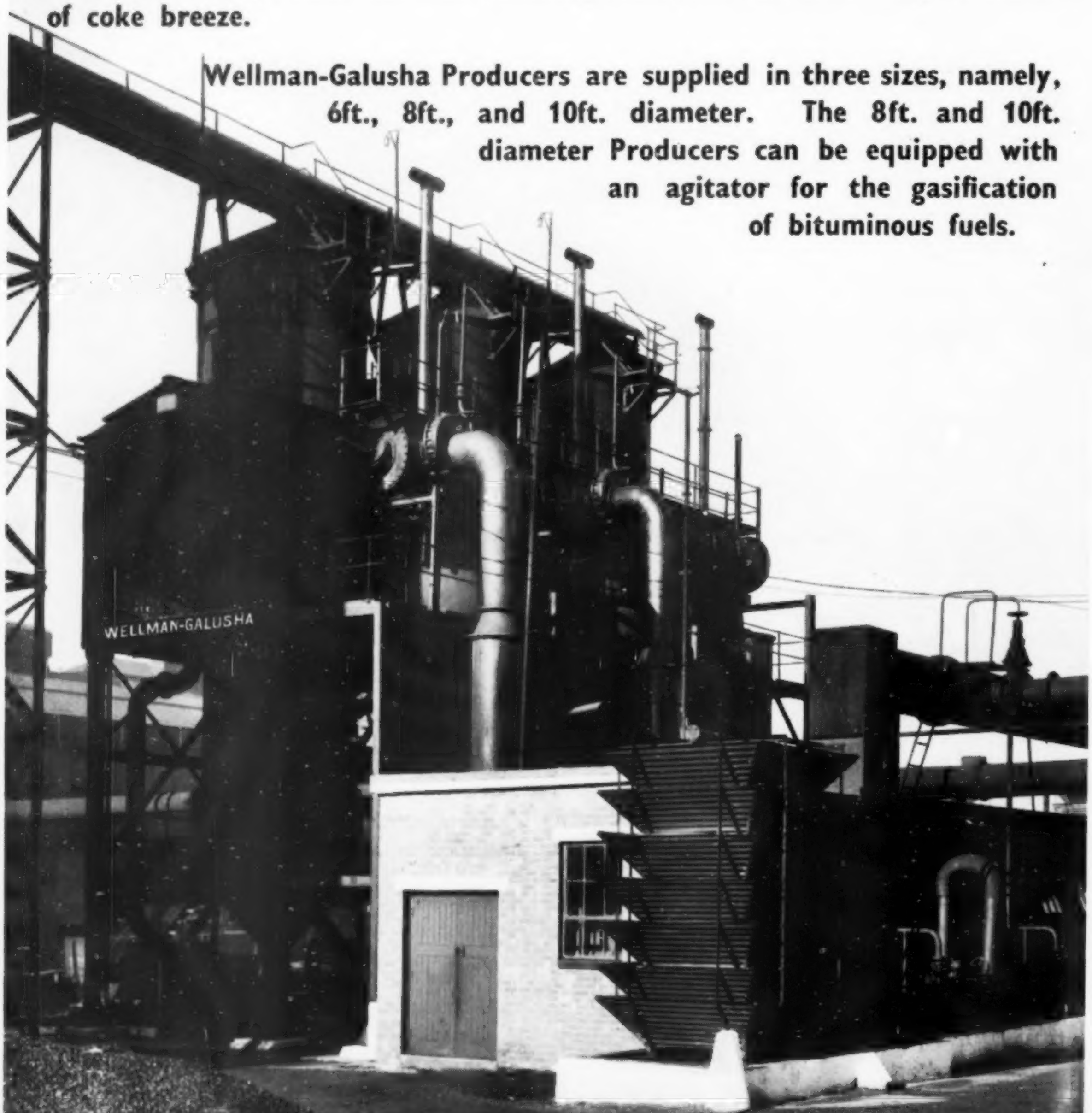

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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE "METALLURGICAL ENGINEER."

NOVEMBER, 1950 Vol. XLII No. 253

This Anniversary Issue

THIS issue of METALLURGIA represents the 21st anniversary of its publication, an anniversary which, when applied to a person, is generally referred to as "coming of age," and in such circumstances, it offers the writer an excuse for a more personal approach to readers. When the writer accepted an invitation to become editor of this new journal, in 1929, it was with the firm conviction that there was need for a publication, at regular intervals, in which could be discussed problems of laboratory and workshop. Metallurgy had come out of the laboratory and was invading the various departments, such as the foundry, forge, mill, and heat treatment, machining and finishing shops, and it was considered that, as operations became more specialised, there was need for a general unifying source of information to connect the various operations in these departments. Thus, the primary object in commencing this journal was to form a bridge between the laboratory and the workship, to consider metal in all its forms, from production in bulk form through the various operations to finished and semi-finished components and products, and to deal with all forms of plant and equipment which the various processes involved. Its editorial function, therefore, was to discuss developments, especially in ferrous and non-ferrous metal production, melting practice, welding, and heat treatment methods; to discuss research and development in the iron and steel industry, the foundry industry, the non-ferrous metals industry, and the light metals industry; and, since the machining properties of metals are characteristics which must be considered in applications, it seemed logical to include machining development as an extension of the metallurgical aspects. With regard to the production of such a journal, it was thought that technical journals published in Britain, at that time, suffered in comparison with many published overseas and yet there appeared no adequate reason why a high-grade technical journal should not reach the standard of a really beautiful production, which could be read and studied in comfort.

With this definite policy in mind, many of the foremost metallurgists and engineers were consulted before a final decision was reached to proceed with the idea, and there was remarkable unanimity of opinion as to its potentialities. The initial support was both encouraging and gratifying and the debt owed to many who have kept a watching brief on the journal and helped with their criticism and encouragement is incalculable. Elsewhere in the present issue Dr. Wernick refers to the comments of a distinguished man in the field of metallurgical journalism, on the appearance of the first issue of this journal. Another well-known editor expressed the same opinion in the writer's presence, but in somewhat different language.

Although the prophecies of these well-known editors were unfulfilled, they were justified in their assumption, and it was largely as a result of the counsel, help and encouragement received, without stint, from contributors and readers, and from advertisers, that it was possible to maintain, and even improve on, the standard originally set, and thus weather the depression. There is a temptation to mention the names of those whose help proved invaluable, either in counsel, expressing opinions on contributions on complex subjects which had been offered, preparing articles at short notice on subjects designed to provide a reasonable balance in any particular issue, indeed, in connection with many aspects of the ferrous and non-ferrous metals industries and processes upon which reliable information was needed by readers of the journal. For obvious reasons the temptation must be resisted, but death has unfortunately claimed some of our most ardent counsellors and supporters and in mentioning Dr. W. H. Hatfield, Dr. T. Swinden, Sir Robert Hadfield, Mr. J. G. H. Monypenny, Dr. Rosenhain, Mr. D. C. Dews, Dr. Donaldson, and Mr. A. Glynne Lobley, as they come to mind, the writer may be forgiven, for paying a richly deserved tribute.

Since the writer believes that the format of a technical journal is shaped largely by its readers the views of correspondents have always been welcomed, particularly constructive criticism; indeed, changes have been made, as a result of useful suggestions. In our initial issue it was emphasised that subsequent issues would differ in important respects and new features would be introduced. This was necessary because the ideal originally set out to achieve was placed at such a high level that it has not yet been reached, but continued effort may ensure its attainment. On one point our readers will agree that a high level of production has been maintained, and, in this direction, the quality of the journal has probably helped to bring about a welcome change in the production of technical journals generally, in this country, in the last 20 years. Another point concerns our policy regarding the literary contents and advertisements, these are in the control of separate departments and descriptions of new plant are published without fear or favour. Having mentioned that fact does not prevent the writer expressing appreciation for the support given through the years in the advertisement pages. It is pleasing to note that nearly all those firms represented in the first issue are to be found in the present issue.

This present issue to commemorate the occasion is a review issue covering a rather broad field, even so there are important omissions, due largely to difficulties beyond our control, but there is ample evidence given in the reviews that the metal industries, on both production and operational sides, have made great progress during the comparatively short lifetime of the journal. We take this opportunity of thanking, not only those who have so ably contributed to the present issue, but to all who have assisted through the years, and who have materially assisted in the publication of a journal which we believe can rightly claim to be of a high order. METALLURGIA will keep faith and will endeavour to be worthy of the great industries it serves.

Progress in the British Iron and Steel Industry

By a Special Contributor

Developments in the British iron and steel industry during the last two decades have been truly remarkable. In the early part of this period world trade was in a deplorable condition and the industry was operating at little more than half capacity. To-day, it has more than doubled its output; its organisation has been vastly improved; new plants have been put into operation and others modernised; considerable technical advances have been made in production and quality of products; all of which reflects credit on managements and men for an achievement of high order.

FEW will doubt that the most outstanding contribution to Britain's post-war industrial recovery efforts has been made by the iron and steel industry. However much the uninitiated may decry the remarkable achievements of this industry, its efforts have been mainly responsible in providing the vital materials which have enabled exports of manufactured products to increase beyond expectations. Many do not realise that iron and steel production in this country provides a useful trade barometer; since the war the need to export goods has made heavy demands on the industry and as much steel as could be produced has been absorbed. This has not only enabled it greatly to increase its production capacity but to keep the plants operating at practically full capacity and thus to maintain price levels for its products that are about the lowest in the world. Low costs are only possible when the plants are in full production and the maintenance of the immediate post-war demand for British products from overseas countries is necessary for maximum output. There were indications of a less favourable position just at the time sterling was devalued, sufficient for many to realise that any recession in world trade would quickly react on the iron and steel industry.

Those familiar with conditions about the beginning of 1930 will appreciate the connection between world trade and the iron and steel industry. At that time trade was in a deplorable condition and iron and steel plants were operating at little more than half capacity. British production costs were said to be higher than those on the Continent because working hours were shorter and wages higher, with the possible exception of Germany. This latter country was cited as being more favourably placed to compete with this country; it was not because of lower production costs that the German iron and steel industries maintained their production near to capacity, but rather to the fact that they were organised as syndicates which collaborated with a view to facilitating exports and the trade was supported by rebates, bounties and subsidies. Efforts were made by the British plants to cope with competition from abroad; much was said about rationalisation by the amalgamation of firms, the closing of apparently redundant works, and the installation of new and the modernisation of existing plant. But the industry had been under a cloud for some years and reorganisation efforts were slow in being put into operation, largely because surplus steel products of other countries were allowed to be dumped in this country at a cost lower than the cost of production.

The iron and steel industry had long contended that the economic factors causing the industrial depression in Britain were not within its control. Indeed, the sub-committee of the Sankey Committee, which had been appointed by the Government to investigate the condition of the industry, emphasised in its report that British iron and steel manufacturers had, for many years, been carrying out research work with a view to effecting real economy. It is noteworthy also that a sub-committee of the Civil Research Committee, after visiting steel works in five continental countries and comparing the plants with those in this country, reported that as regards efficiency and management and the modernity of equipment of certain units of plants, they were equal to, and in some cases superior than, the steel plants they had seen on the Continent. At that time it must be remembered that the industry was offering its products at between 15 and 20% above pre-1914 prices, while the corresponding increase in the cost of coal varied between 25 and 75%, labour from 66–100%, and rates and taxes from 100–300%. In this respect it is surprising how history is repeating itself to-day.

Although considerable efforts had been made to re-establish the industry at that time, development was retarded by the world-wide trade depression and by the knowledge that, under free trade, foreign materials were being dumped in this country at less than production costs. With a view to improved organisation several firms had amalgamated, but, with exceedingly low outputs and no degree of security in the home market, it was only possible in a few cases to embark upon extensive schemes of reorganisation. Steps were ultimately taken to consider raising world price levels of commodities and to ensure that competition in the home market at least, would be legitimate in character and based on efficient production and an Advisory Committee on Tariffs was appointed. The recommendations of this Committee published in 1932 emphasised that the maintenance of a prosperous iron and steel industry in the highest degree of efficiency is essential to the economic progress of Britain, whilst from the point of view of national security it must be regarded as vital and the temporary duties subsequently imposed certainly stimulated confidence in the industry.

A $33\frac{1}{3}$% duty was imposed on imports of certain classes of heavy iron and steel products; meanwhile a National Committee was appointed to prepare a more definite scheme that could be accepted as a permanent means of protecting the industry, without injury to the home user. A report of the finding of this Committee was published in 1933; this contained a scheme which embraced the formation of twelve associations, each dealing with a group of products coordinated by the formation of a

corporation to be so organised that it would give a reasonable balance of interests to the producing and consuming sections of the industry. It was the considered opinion of this Committee that the orderly progress of the industry could only be secured by the regulation of production in relation to demand, both by international agreements and also, even within the protection of the tariff walls, by applying some degree of control to the individual producers of each country. The British Iron and Steel Federation was constituted to carry out this scheme.

The departure of Britain from its traditional free trade policy had the inevitable result of approaches from many countries desirous of revising their trading agreements, most of which were from European countries, and by the end of 1933 there were indications of improvement in trade on which recovery of the iron and steel industry depended. Although international trade does not necessarily follow home trade expansion, and the imposition of tariffs, quotas, exchange restrictions and fluctuating currencies hamper the exchange of goods and manufactures, a definite improvement was discernible even in international trade. Of the iron and steel industry it can be said that protection had given it a means of bargaining which it had not previously possessed and established conditions that created a spirit of hope and confidence within the industry.

There was more evidence of improvement in 1934 largely following the adoption of tariffs but also due in no small measure to the abandonment of the gold standard, but the task of reconstruction could not be given effect at once, in any case the recovery of world trade was an international problem and the iron and steel industry could only progress as world economic changes gave the proper impetus to the freer exchange of goods and manufactures. Various reorganisation schemes had been put into operation, others were in hand, but the increased confidence in the industry was in evidence by the increased number of schemes which included much new plant.

This forward movement was gradual at first, but, as the world's economic difficulties became adjusted to the changes, it increased in momentum and left the bitter and cruel years of depression behind. The obstacles to the reorganisation of the iron and steel industry, for instance, that at one time appeared to be insurmountable, were gradually overcome. By early 1939 the recovery had become so great that a condition of industrial boom was claimed to exist in Britain. All industries and districts shared in this improvement and it was confidently asserted that boom conditions would continue, however the international outlook remained unsettled and war in Europe, which seemed inevitable despite this country's peaceful efforts, again involved us

1939—1945

Abnormal requirements for war purposes intensified industrial activities in all districts, although some time was occupied in adjusting production to the system which gave priority to Government orders. The demand for steel imposed by war necessitated the early adoption of a distribution scheme in order that the best use could be made of available supplies. It was fortunate for the country that considerable enterprise and initiative had been displayed in reorganising this industry and in a comparatively short time production was at peak levels, with rapidly increasing output of alloy and special steels for a great diversity of war purposes. It must be remembered that high production was accomplished in the face of unprecedented raw material difficulties, particularly with the fall of France when about four-fifths of its raw material resources were cut off, shortage of labour, blackout conditions and unpredictable changes in demand imposed upon the industry, at very short notice, by the urgent requirements of war.

The emergency of war necessitated reconsideration of world supplies of raw materials used in making alloy steels. The whole field of alloy steel consumption was reviewed and the various compositions and properties were scheduled according to uses. For this purpose a Technical Advisory Committee was appointed and its efforts resulted in a substantial reduction in the number of special and alloy steels. The two thousand or more different steel specifications contained in the records of the British Standards Institution were reduced to about ninety, and, since these were based on the availability of alloying elements and other special materials, it was possible to allocate raw materials on an equitable basis and to facilitate the placing of orders for any one of the ninety specifications.

The cutting off of Spanish and Moroccan supplies of iron ore was serious and alternative sources had to be brought into operation, some of which inevitably involved long haulage, and, with an acute shipping position, the use of the low-grade high-phosphorus home ore was intensified.

The successful prosecution of the war made increasing demands on the industry ; from the beginning emphasis was on increased steel production, and by taking extraordinary steps, not only by installing new plant, but by increasing the output from existing furnaces, by reducing the time per heat and increasing the number of heats before shutting down for repairs to lining or roof, the industry did a tremendous job of work to meet the nation's need. In converting the steel into the various finished and semi-finished forms needed its efforts were not less vital and in these efforts major technical problems of great complexity were encountered.

Post-War Developments

Since the end of the war the primary concern of the industry had been, and still is, efficiency in production. During the war normal progress was hampered by more pressing production needs and many of the reorganisation schemes initiated before the war were held up because of the time factor and labour involved in producing the new equipment needed. In some cases plant erections in progress at the beginning of the war were rapidly completed, and methods for increasing the output from existing furnaces, with the least possible effort, were adopted, but long range schemes were of necessity held up. Apart from this, however, existing plant and machinery had been overburdened during the war to meet abnormal demands and needed thorough overhauling or renewal, which involved modernisation and much new construction. But the change from war- to peace-time activities brought no respite to the industry since practically all other industries depended upon its products to enable them to make the transition with the least possible delay. Thus, more than any other industry the iron and steel industry has been called upon to carry out delayed reorganisation and reconstruction, while at the same time maintaining a high level of production. That it has been successful is now fully

realised; progressive managements and workers in the industry, in co-operation, have repeatedly established production records for them to be quickly broken by the achievement of new high levels.

The industry was fully alive to the production problems that faced Britain at the end of the war and, without waiting for them to develop, prepared re-organisation schemes which could be put into operation without delay. The plan was submitted to the Ministry of Supply as a report from the Iron and Steel Federation and was subsequently issued as a White Paper. The three main objectives of the plan were: to make good the further modernisation and development which would have taken place had there been no war; to enlarge steelmaking facilities and bring them into close relationship with the anticipated demand for steel products; to ensure the most effective use of plants by concentrating production into efficient units of suitable size, having due regard to the availability of raw materials and the distance to markets. It was considered that the whole industry could be renewed by 1950, and the industry was fully aware of the difficulties such a plan imposed, arising from the fact that it was to be undertaken in the post-war period of re-adjustment and during a time when construction costs were expected to be abnormally high.

The plan as a whole had been carefully balanced to provide units of efficient size, the most effective degree of concentration, the full loading of efficient plant and the maximum reduction in fuel consumption. It involved the building of 4,750,000 tons of blast furnace capacity and about 6,000,000 tons of ingot capacity. The initial expenditure contemplated was £168 million, but it is probable that rising costs and modification to the original plan have increased this amount to over £200 million. It will be appreciated that no plan intended to be executed over a period of years could be strictly adhered to in every detail as the years passed; the industry's schemes have inevitably been subject to revision in the light of changing economic and technical conditions. Even the rapidly rising capital costs led to certain re-casting of plans.

Gradually, as new and modernised plant has been brought into service, production has increased and output records made only to be broken shortly afterwards. In October this year, for instance, steel production was at the annual rate of 17,040,000 tons, the highest ever obtained in any October month; only once before had the 17 million ton mark been exceeded—in March this year the figure was 17,147,000 tons. New and modernised plant has naturally incorporated technical advances and improvements developed to some extent during the war period, most notable of which are the increased size of blast furnace units and the application of continuous rolling to sheet production.

Plant Improvements

The size of blast furnaces has been steadily increasing for some years and at present the limit appears to be 28 ft. diameter, with an approximate capacity of 1,200 tons of pig iron per day, when all conditions are favourable. Many new and modernised blast furnaces, with hearth diameters exceeding 20 ft., have been put into operation. Output has been greatly augmented by the increasing care being exercised in the preparation of ore; not only is attention being paid to the most suitable average size of the ore but also to the removal of fines and subsequently treating them in a sintering plant. Increased attention has also been given to mechanical handling and charging of the raw materials. Furnace linings have been greatly improved; a number of all-carbon furnaces have been in blast for some considerable time and since they were so lined the output has increased 10–15%, indeed the success so far achieved with refractory carbon linings seems to indicate that their use will ultimately become standard practice. Other methods likely to increase production are being studied; for instance, there is much interest being shown in pressure blowing with a view to an increase of top pressure, which is claimed to increase output.

Apart from minor modifications, particularly in port designs, the general design of open hearth furnaces has remained static for many years, but whether fixed or tilting furnaces are used for steelmaking depends to some extent on the amount of scrap available. When a high percentage of pig iron must be used and the percentage of phosphorus in the charge is relatively high the tilting furnace is preferable because of the increased slag. In general, however, fixed type furnaces for the acid process, while either fixed or tilting types are in use of the basic process, with the trend towards the tilting type because the scrap position is likely to become more difficult. The trend during the post-war years has been towards larger units—up to 350 tons—but the smaller furnaces have advantages for making special steels, especially when made by the acid process.

Although reference has been made to acid open-hearth furnaces their use is steadily declining because of the growing scarcity of low phosphorus ore for making hematite iron. High-grade steels with low sulphur and phosphorus contents are being increasingly made in electric furnaces and there can be no doubt that present trends are towards a substantial rise in electric steel ingot production. In the comparatively near future electric furnaces up to 50 tons capacity may be expected to contribute to the country's need. The use of oxygen in raising output of electric steel is very promising.

The full scale investigations carried out in all-basic furnaces have shown that the average working temperature of such furnaces can readily be increased about 100° C. above that for furnaces lined with silica brick, and this enables the furnaces to be worked faster which leads to increased production. There are, however, disadvantages; the refractories are destroyed more rapidly and they are more costly than silica, but further study of this problem may provide a solution such as to make the all-basic furnace justifiable economically.

Although there have been no revolutionary changes in rolling practice comparable with continuous mills, there has been steady improvement in details of design. Mills are larger and built for greater speed in operation and, in view of the high cost of coal for steam engine drives, the choice of power since the war has, almost invariably, been decided in favour of electricity. The electric drive has many advantages in the rolling mills, particularly the ease of control. In all the main producing areas, special attention has been given to rolling mill installations, the most outstanding being that in South Wales.

Much has been achieved in the period reviewed by the installation of new units, improvements and extensions to existing units, and as a result of a steady increase in technical efficiency, but the valuable co-operation that exists between the men at all levels within the industry has contributed, in no small degree, to progress that is outstanding in outlook and performance.

Twenty-One Years of Progress in Special Steels

By D. A. Oliver, M.Sc., F.I.M., F.Inst.P. and J. S. Bristow, B.Sc.

(William Jessop & Sons, Ltd., Sheffield)

Despite the fact that, during the past 21 years, sensational discoveries in special steels are lacking, existing types have been ably developed so that many new steels have appeared having extended applications. Some of these developments are referred to in this survey and credit is given to the hard and painstaking work of enterprising research organisations as well as to the inventive genius of the British race.

FOR over two decades METALLURGIA has served its readers well by presenting, from time to time, review articles on advances in special steels which have taken place during the preceding two or three years. If, however, a conscious attempt is made to focus the advances of the last twenty-one years, it is illuminating to note the considerable changes and substantial progress of that period. Many new compositions and techniques, having been absorbed into the industry, have become so part and parcel of it that one is amazed, even shocked, to realise that their application is only a comparatively recent event.

Let us glance at the position of special steels as it was in 1929. Molybdenum had been accepted as an alloying element some three years previously, and its presence in alloy steel compositions was then universally recognised. Stainless steel was being rapidly developed and was finding an increasing number of applications. It was about this time that the phenomenon of "intercrystalline corrosion" or "weld-decay" was observed in the austenitic types and was exercising the minds of research metallurgists at home and abroad. Nitriding steels were arousing commercial interest, but had not yet been widely applied on a production basis. In magnet steels the 6% tungsten, the 35% cobalt and the lower cobalt-chromium types held the field predominantly, but many 1% carbon steel magnets were still made and used. Heat-resisting steels had been studied during the previous nine or ten years, and chromium-nickel austenitic steels had been developed for this purpose. It had already been ascertained that high percentages of chromium and nickel were insufficient in themselves, and that additions of other elements such as tungsten and titanium were necessary to confer mechanical strength and other valuable properties at elevated temperatures. It is interesting to note that in 1929 an event occurred which was later to prove perhaps the greatest incentive to the development of new types of heat-resisting steels, namely the invention by Sir Frank Whittle of the first practical jet engine.

Engineering Constructional Steels

The compositions of alloy steels for engineering constructional purposes have not basically changed during the last 21 years, but the demand for increased hardenability, particularly by the automobile industry, has led to intensive development of the heat-treatment of these steels. The processes of "martempering" and "austempering" have arisen during this period. Attempts have also been made, especially in America, to increase hardenability by the addition of traces of boron. While certain casts of mild steel treated in this way have been produced which possess the hardenability of low-alloy steels, the results were not reproducible, and inferior elongation and impact values have been noted. For assessing hardenability the Jominy end-quench test

Fig. .—The Gloster Meteor speed-record plane. The Rolls-Royce Derwent V jet engines symbolise the fruits of progressive metallurgy.

was developed, and has proved a good and rapid practical means of ascertaining the capabilities of a steel. The rather extravagant claims of some investigators, however, have not been substantiated for predicting a wide range of mechanical properties in different heat-treated sections from the curve obtained by a single end-quench test.

As might be expected, a multiplicity of alloy steel specifications arose from the consumer industries according to individual requirements. During World War II, due to the necessity for conserving ferro-alloys and electrical energy, it was the task of the TAC (Technical Advisory Committee of the Special and Alloy Steels Committee of the Iron and Steel Control, Ministry of Supply) to reduce the immense number of specifications in existence to a few standard formulae. The result was the En series of specifications of B.S. 970. The success of this achievement was not so much the fact that some 1,500 specifications were covered by the series of a mere hundred odd, but that tables were provided showing which steels would give certain tensile properties in various heat-treatment sizes. Thus if mechanical properties in the 60 tons tensile range were required in 2½ in. sections, then it was unnecessary to employ 3% Ni–Cr–Mo steels, because manganese-molybdenum or 1% chromium-molybdenum steel would fulfil the conditions. The user was further assisted by the publication in B.S. 971 of information on the heat-treatment and manipulation of these steels, including tables for converting rectangular sections into equivalent rounds for assessing heat-treatment sizes. These considerations have had the effect, not only of conserving rare and valuable alloys during war-time, but conferring as well continuing economies for the steel-user and easing the work of the designer and engineer.

Free-Cutting Steels

Screws and other small machine parts are now universally made by automatic machine-tools, and many attempts have been made to provide steels for this purpose which will machine with a short chip length. Additions of sulphur and phosphorus have been successful in bringing this about, but at the cost of the transverse mechanical properties of the part. In 1937 and onwards lead was introduced into carbon and alloy steels for this purpose and greatly improved machining properties have been obtained. The transverse properties are still affected somewhat, especially at elevated temperatures of, say, 350° C. An important advance in free-cutting alloy steels was the modification about eight years ago of the standard 12/14% chromium martensitic stainless steel. About 0·5% sulphur (with additional manganese) was added and supplemented with about 0·30% zirconium (added as silico-zirconium) to convert the majority of tne sulphur present into zirconium sulphide. Delightful machining conditions resulted and a high degree of surface finish was obtained without grinding.

Selenium, molybdenum sulphide and niobium (columbium) have all been added to austenitic 18 : 8 stainless steel and its variants to improve machinability. Selenium has now been largely discarded on account of its toxic effects in steelmaking.

Tool and Die Steels

Since the initiation of high-speed tool steels, the development of this branch of special steels has consisted very much of variations on a theme, with tungsten as the predominant element. During World War II, when this element was both difficult and expensive to obtain, molybdenum was substituted for it, following a friendly lead from the U.S.A. At first, the results obtained were indifferent as the products were handicapped by a soft skin layer. This, however, was overcome by varying the heat-treatment and paying attention to furnace atmosphere conditions. A comparatively new steel having special wear resistance is Jessop J.13 which has the following composition: Carbon, 1·2%; Tungsten, 14%; Chromium, 4·3%; Vanadium, 4·5%. This high-speed steel is being applied with conspicuous success in all applications where steels in the 50/100 tons tensile condition have to be machined. It has also proved eminently satisfactory for machining the Nimonic alloys at low feeds and speeds. The additional carbon, combined with 14% of tungsten, the chromium and the high vanadium content, imparts exceedingly good abrasion resistant properties. High-speed steels with vanadium contents up to 5%, together with 5% of cobalt, are also being successfully developed. They possess high initial hardness and maintain their cutting edges for longer periods than other high-speed steels, and, moreover, have increased hot hardness.

For hot-work steels, additions of molybdenum have been found superior to tungsten for certain types of extrusion dies. In the cold-work tool-steels, additions of 1% molybdenum and up to 0·5% vanadium, to the standard 1·5% carbon 13% chromium type, have conferred increased toughness. Among the air-hardening cold-work steels, a high manganese steel has been recently developed. Graphitic types have had as yet few applications in Great Britain, but since they possess (due to the presence of free graphite) low frictional properties, high resistance to wear, and ready machinability, they could be employed advantageously for cold-heading dies, cold-drawing dies, and all types of press tools. It is difficult to do justice to this wide field of tool steels without going into the refinements of the compositions and the heat-treatments of many steels, which are outside our scope.

Permanent Magnet Steels

In 1931, Mishima in Japan discovered the extraordinary magnetic properties of a ternary alloy of iron having 29% nickel and 13·5% aluminium. About the same time, investigators in the U.S.A. and Germany made similar discoveries with alloys of iron and cobalt with tungsten and molybdenum, but these proved uneconomic for general commercial use at the time. Horsburgh and Tetley in Sheffield in 1934 studied the effect of adding cobalt and copper to the nickel-iron-aluminium alloy studied by Mishima. The result was British "Alnico," containing approximately 18% nickel, 10% aluminium, 12% cobalt, 6% copper and the remainder iron. Since these alloys are nearly carbon free, they are not strictly speaking "steels," but they are certainly "ferrous alloys" and probably have as much right to be considered as "special steels" as some of the high nickel-chromium "steels" which contain only a small percentage of iron.

In 1938, Oliver and Shedden studied the effect of cooling Alnico from a high solution-temperature in a strong unidirectional magnetic field. The effect obtained was definite although small, and the first anisotropic permanent magnet had been produced. Philips at Eindhoven, Holland, contributed greatly with the

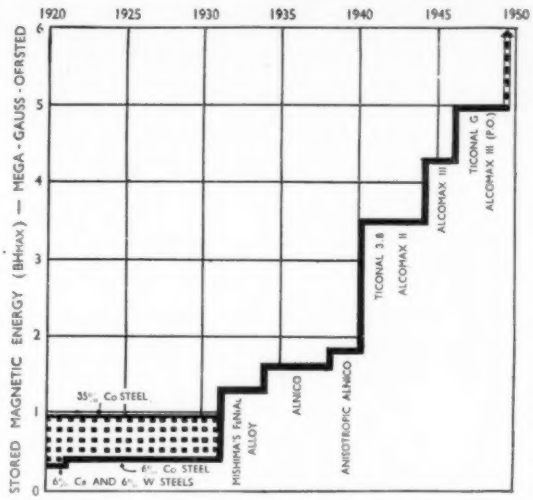


Fig. 2.—Diagram illustrating the trend of magnet steels and alloys to higher values of magnetic stored energy—(BH) max. per unit volume.

advent of the Ticonal alloys whereby the magnetic stored energy values "(BH)*max*" were advanced from from 1·6 to 3·8 million, consequent upon the discovery of the advantages of a high cobalt content in the range 21/25%. Alloys with still greater energy contents and associated with higher coercivity values, have followed the recent discovery by Oliver and Hadfield (1948) that additions of niobium are beneficial, and these stable alloys are now in full commercial production in Great Britain under the names 'Alcomax III' and 'Alcomax IV.' A diagram showing the remarkable advances over the past three decades is given in Fig. 2.

Recent progress by Hoselitz and others is opening out still greater possibilities by controlled crystal-growth giving preferred orientation before the magnetic heat-treatment is imposed. (BH)*max* values of over 8 million have been obtained experimentally and applied research is currently endeavouring to evolve suitable production methods. Powder metallurgy has also contributed to the economic production of very small permanent magnets in the newer alloys. During World War II, with a view to saving wolfram, the Germans developed a magnet steel with 1% carbon, 0·25% manganese, 3·8% chromium, 0·5% tungsten and 2% cobalt, as a substitute for the well-known 6% tungsten magnet steel. This steel has been successfully and widely employed during recent years.

Heat Resistant Steels

It is possibly in this field that the most spectacular developments in special steels have been made. Even before jet-engine requirements were made known, aero-engine designers and others were making demands for steels for valves in internal-combustion engines, which would stand up to high stresses at elevated temperatures without serious extension, would resist scaling, and would retain a stable structure. An obvious necessity for the investigation of such materials was a short-time test for determining the "creep" of steels at high temperatures, and with this in view, the late Dr. W. H. Hatfield, F.R.S. in 1930 proposed a method whereby the stress was determined by the static loading on a test-piece held at the required temperature, such that the elongation of the gauge-length did not exceed 0·5% in the first twenty-four hours, and a creep of a millionth of an inch per inch per hour was observed in the next 48 hours. This stress was termed the "time-yield." This method, by which a test could be carried out in the space of three days, was widely adopted at that time for determining the creep resistance of many steels and in turn the accumulated data stimulated the quest for still further improvements.

For temperatures up to 550° C., ferritic as well as austenitic steels were quite satisfactory, and no great difficulty was experienced in finding austenitic steels for duty at 650° C. One of the problems experienced in developing austenitic steels for high temperature work was to overcome the phenomenon of intercrystalline corrosion or weld-decay. 18:8 chromium-nickel steels, particularly those with higher carbon contents, when cooled slowly or submitted to red heat after softening, were subject to chemical attack by corrosive fluids in chromium-denuded zones due to the formation and deposition of chromium carbides along the grain boundaries. This was overcome in the early 1930's by reducing the carbon content to a minimum and by adding carbide-forming elements, such as titanium or niobium, which were stronger in their affinity for carbon than chromium. In certain aero-engine steel specifications, conditions for intercrystalline corrosion tests were laid down, although the method of overcoming the phenomenon was largely left to the steelmaker. The modern version of the test is often called the "Strauss Test."

As the demands on heat-resisting steels increased in intensity, compositions became more and more complex, but the greatest fillip for further research came with World War II, when the development of the jet-engine, previously held-up due to lack of suitable materials, became a matter of national importance. The researches which were carried out on this problem have already been fully described, and it is intended to give here a brief summary only of the progress made. R.ex 78, one of the steels used for the inlet nozzle and rotor blades in Whittle's experimental turbines up to 1943, is still employed on a small scale for inlet nozzle blades, where resistance to scaling is the first consideration. Modern practice for this purpose favours Nimonic 75, HR Crown Max, R.22 or G.18B. Nimonic 80, one of the Nimonic alloys originally developed in 1942, has been found most suitable for rotor blades. More modern versions are Nimonic 80A and Nimonic 90. A recently developed alloy steel (G.32) possesses attractive properties, especially as regards hot-fatigue, and is also being made available for rotor blades. All these alloys have the disadvantage of being machinable only with great difficulty. The problem has to some extent been side-stepped by making the inlet-nozzle blades for gas turbines as "precision castings" by means of the "lost-wax" process. The blades so manufactured need only a minimum of grinding before they are ready for assembly. This process, originally developed in its modern form by dental mechanics, has been intensively developed and applied for gas-turbine blades and heat-resisting parts during the last ten years.

As regards gas-turbine discs for jet-engines, it has become almost universal practice to use a complex austenitic alloy steel—Jessop G.18B—first developed in

TABLE I.—SOME STEELS AND ALLOYS USED IN GAS TURBINE CONSTRUCTION. (WT. PER CENT.)

	C	Si	Mn	Ni	Cr	Co	W	Mo	Nb	V	Ti	Cu	Fe	Al
R.ex 78	0·08	0·7	0·8	18·0	14·0	—	—	4·0	—	—	0·6	4·0	Bal.	—
Nimonic 75	0·10	0·8	0·3	78·0	20·0	—	—	—	—	—	0·3	—	<5·0	—
Nimonic 80	0·04	0·5	0·6	74·0	21·0	—	—	—	—	—	2·5	—	about ·5	1·2
HR Crown Max	0·2	1·6	0·4	12·0	23·0	—	3·0	—	—	—	—	—	Bal.	—
R.22	0·3	1·3	0·9	14·5	25·0	—	3·2	—	—	—	—	—	,,	—
G.32	0·3	0·5	0·8	12·0	19·0	45·0	—	2·0	1·2	2·8	—	—	,,	—
G.18B	0·4	1·0	0·8	13·0	13·0	10·0	2·5	2·0	3·0	—	—	—	,,	—
H.3A	0·57	1·2	0·5	—	6·1	—	—	0·5	—	—	—	—	,,	—
H.27	0·4	0·3	0·6	—	3·0	—	—	0·8	—	0·2	—	—	,,	—
H.31	0·4	0·3	0·4	—	1·1	—	—	0·7	—	—	—	—	,,	—
H.40	0·25	0·4	0·4	—	3·0	—	0·5	0·5	—	0·75	—	—	,,	—
H.46	0·15	0·4	0·3	—	12·0	—	—	0·5	0·15	0·75	—	—	,,	—

1943. This steel has been proved successful under high-stress, high-temperature conditions with a minimum of rim-cooling present.

Due to the somewhat lower temperatures and less stringent conditions under which many gas-turbine discs operate, it is also possible to employ special ferritic alloy steels. Successful results have been obtained by forging and machining discs from H.3A, H.27, H.31, H.40 and H.46 steels. This approach has the advantage that ferritic steels are relatively easy to forge and machine, and can be reliably hardened and tempered. For highly stressed discs, H.40 or H.46 is the obvious choice. Each possesses high creep-strength and H.46 steel has also a high scaling resistance. The compositions of the steels referred to are given in Table 1.

General

Among the developments which have taken place in the last twenty-one years, but which are not necessarily confined to special steels, may be mentioned the advent of non-destructive (ultrasonic) methods of testing; the investigation of the cause of hair-line cracks in relation to hydrogen; the method of assessing the 'cleanness' of a steel by inclusion count, initiated by G. R. Bolsover in 1936; and the study of the behaviour of steels at sub-zero temperatures. The more recent developments in extra-high-altitude aircraft have emphasised the importance of obtaining more complete data at low temperatures. Much work too, has recently been carried out on the machinability of steels, apart from free-cutting materials. The question of over-heating in drop-forgings has also been considered, and it has been shown in general that clean electric-arc steel is less susceptible to this effect than open-hearth steel.

In surveying the developments of "special steels" over the last twenty-one years, despite the fact that sensational discoveries such as Hadfield manganese steel and Brearley stainless steel are lacking, it is clear that existing types have been ably developed so that many new steels have appeared, having extended applications. On reflection, it will be realised how much credit is due to the hard and painstaking work of enterprising research organisations, as well as to the unfailing inventive genius of the race.

Carbon and Low Alloy Steels

By I. M. Mackenzie, B.Sc.

Developments in the field of carbon and low alloy steels, during the past 21 years, have been greatly influenced by the impact of such problems as weldability and brittle fracture. On the production side, oil-firing, combined with greater instrumentation and improved refractories, has led to greater output.

MILD steel, being the basic material employed by both the heavy and light engineering industries, has been produced by mass production methods for longer than most other products. Although mass production reduces costs, it inevitably tends to restrict technical development for two reasons. Firstly, products are standardised to permit the use of repetitive processes. Secondly, the heavy capital investment in equipment acts as a deterrent to the modification of manufacturing procedures. These factors have influenced the development of carbon and low alloy steels during the past twenty-one years and may be expected to continue to have an important effect.

The standardisation of design procedures by the consumer has also increased the difficulty of introducing new products. For instance, the design of most structures is based on the ultimate tensile strength of the steel, factors of safety being determined from observation of the behaviour of structures. As design calculations are based on the ultimate tensile strength it is a natural consequence that this property has been chosen as the criterion for acceptance tests for batches of steel. To-day, though it has been shown that the yield stress is in many cases a more reliable criterion of load carrying capacity, many inspection agencies continue to consider only ultimate tensile strength, thus hampering the development of higher strength structural steels. Thus a number of developments which are both technically feasible and potentially profitable have been delayed by the inevitable conservatism of the complex producer and consumer industries. Despite these handicaps, progress has been made in many fields, but this has been due generally to the prompting of economic and strategic demands rather than by advances in metallurgical science.

There has always been an economic incentive to employ high strength steels for structural applications, since savings are to be effected in the weight of steel used, transport, fabrication and operating costs, etc. In 1934 a British Standard Specification was drawn up for a structural steel with a yield strength exceeding 23 tons/sq. in. (B.S.S. 548). The higher strength is generally obtained by increasing the carbon and manganese contents above the range normally employed

for mild steel. The higher manganese content ensured the maintenance of adequate ductility and toughness. Steels complying with this and other comparable specifications have been used for the construction of ships, bridges, railway rolling stock, etc. Fabrication was generally by riveting since it was conceded that the steels were not suitable for oxyacetylene and electric arc welding procedures. With the increased adoption of the latter welding process it was found that, to avoid embrittlement or cracking in welded joints, it would be necessary to sacrifice some strength in order to obtain a greater margin of safety in weldability. This led to the introduction of B.S.S. 968 in 1941, providing for steels with a somewhat lower yield stress but stipulating that the carbon content should not exceed $0{\cdot}23\%$ max. In consequence of this limitation of the carbon content the consumer is enabled to employ arc welding with confidence. The weldability of the steel is improved by limiting the carbon content because the maximum hardness developed in the heat affected zone adjacent to the weld deposit is thereby reduced.

The requirement for weldability thus led to a recession in the application of high tensile steels. As the technique of welding has been improved and new types of electrode, etc., have come on to the market, a new move towards the development of higher strength structural steels has commenced. It is known that certain alloying elements delay the transformation from austenite to the ferrite plus cementite phases so that it occurs in the bainitic range on air cooling from a high temperature. It was previously considered that steel must be used either after transformation in the pearlitic range or after quenching to a completely martensitic condition since it was thought that steels transformed in intermediate ranges were invariably brittle. It is now known that while this is true of the majority of compositions it is possible to produce low carbon, low alloy steels which transform partially in the bainitic range on air cooling from the rolling or normalising temperature and which have good notch toughness combined with an increased ultimate tensile strength and a high yield ratio. The toughness may be further increased by a low temperature annealing or stress relieving treatment. Since these steels derive their strength from the low temperature of transformation, the carbon content may be kept to a low value which ensures ease of welding.

Since a feature of these steels is the high ratio $\frac{\text{Yield Stress}}{\text{Ultimate Tensile Strength}}$ full advantage is obtained from them only when design calculations are based on yield stress. The extended application of improved design procedures such as the plastic theory for the design of redundant structures, will increase the economic advantage to be gained from the use of high yield steels and stimulate these developments.

A comparable development is the production and application of cold formed sections of carbon and low alloy steels. The greater rigidity of structures fabricated from such components permits a considerable saving in weight.

The problem of brittle fracture of mild steel has engaged a great deal of attention in recent years leading to some interesting developments. The tendency for steel to fracture with little or no plastic deformation was brought into prominence by catastrophic failures of large welded structures such as ships and bridges. It is known that brittle failure is initiated at stress raisers such as notches or sharp fillets, cracks being propagated dynamically so that the steel fractures without exhibiting its usual ductility. Brittle fracture is most likely to occur at low temperatures and where there is shock loading of a rigid structure. While the most serious aspects of the problem have been resolved by modifications to design, particularly the elimination of stress raisers in the form of notches, sharp corners, etc., for certain applications it has been necessary to develop steels which are less liable to fail in a brittle manner.

The notch toughness of a steel is most commonly measured by the Izod or Charpy impact test in which a notched specimen is fractured by a blow from a pendulum, the energy absorption being recorded. The energy absorption, which should be as high as possible, decreases discontinuously as the temperature of testing is decreased and either the temperature of transition from tough to brittle fracture or the energy absorption at some arbitrary temperature may be employed as a criterion of notch toughness. It has been found that poor notch toughness in carbon steels is normally associated with a coarse microstructure or with a low manganese or high nitrogen content. As a first step to ensure adequate toughness in plates used in shipbuilding, Lloyds Register have stipulated that the manganese/carbon ratio for ship-quality plates over $\frac{1}{2}$ in. in thickness, shall not be less than $2{\cdot}5$. The nitrogen content of steels manufactured by the open hearth process is invariably low and no difficulty is encountered with the nitrogen content of British steels since all ship plates are produced by this process. Thick plates rolled in fast modern mills in which hot working is completed at very high temperatures are found to have coarse microstructures and correspondingly low notch toughness. For service under severe conditions, e.g. highly stressed sections of ships' hulls, pressure vessels for use at sub-atmospheric temperatures and structures subjected to explosive loading, it has been found that the notch toughness of thick mild steel plates may be inadequate. For these special purposes one or more of the following measures may be adopted. Plates may be normalised in such a manner that the grain size is refined. This is frequently made easier in practice if grain growth during heat treatment is controlled by the addition of aluminium to the steel. A further improvement may be effected by reducing the carbon content and adding manganese or some other alloying element to maintain the tensile strength. By a combination of these two methods it is possible to obtain notch toughness approaching that of quenched and tempered steel.

Although the most modern steam generating installations are constructed with steam pipes and superheater tubes of special alloy steels, the majority of existing installations operate at comparatively low working temperatures and pressures, using tubes of carbon and low alloy steels. As the efficiency of heat, transfer is dependent on the wall thickness of the tubes any improvement in the creep resistance of the steel will permit modifications to design which will increase the overall efficiency. Several improvements to the steel during the last twenty-five years have made it possible to increase the working stresses at which the tubes may be used. One important development relates to control of the practice of deoxidising the steel as it is run into the moulds. It had been found that the

presence of clusters of silicate inclusions renders the steel unsuitable for the hot piercing process of tube manufacture. Additions of aluminium made to the molten metal prevent the formation of the harmful silicate clusters. While the addition of small amounts of aluminium has no deleterious effect on creep resistance, if an excessive quantity is added the steel becomes fine grained in the McQuaid-Ehn test and suffers a marked deterioration in creep strength. Such steels are said to be 'abnormal' in their creep properties. Now that the effect of aluminium is understood it should be possible to amend specifications in such a way that there will be no danger of abnormal steels being supplied for tubes for service at high temperatures.

The creep resistance of the simple carbon steels can be improved by increasing the manganese content to about 1·5%. A much greater improvement is obtained by the addition of 0·5% of molybdenum either alone or together with 1% of chromium. This small alloy content may as much as double the permissible design stress at temperatures about 900° F.

There has been one striking trend in the demand for carbon steel products. Prior to 1925, the bulk of mild steel was supplied in the form of sections. Due to the requirements of the expanding petroleum industry, and the increased use of steel sheet for car bodies and containers for food and other products, the greater proportion of mild steel is now rolled to plates or sheets. To meet the demand for this type of product, it has been necessary to instal new plant for rolling plates and continuous mills for the cold rolling of sheet. There has been in addition a continued increase in the size and weight of plates used for the construction of ships, pressure vessels, etc. Single plates weighing over 20 tons are now supplied for boiler shells. The production of such plates naturally involves special difficulties, not the least of which is the segregation of carbon and other elements during the very slow freezing of the large ingots required.

The greatest tonnage of carbon steel produced in Great Britain is made in fixed open hearth furances. The design of these furnaces remained static for many years until developments were stimulated by the necessity to convert many of the furnaces from producer gas to oil firing. The hotter flame obtainable from the oil fuel increased the rate at which heat could be transferred to the charge and so increased furnace output. However, this could only be obtained at the expense of damage to the refractories forming the furnace structure. A temporary solution to the problem has been achieved by the increased use of instruments to assist the furnace operator and by water cooling the parts of the furnace which are found to be most susceptible to damage. Water cooling considerably reduces thermal efficiency and increases the capital cost of the furnace and cannot be accepted as a long term solution to the 'refractory' problem. Instrumentation and automatic control prove to be of considerable value once initial practical difficulties are overcome. A skilled operator with reliable instruments to aid him can control a furnace more efficiently than an operator with equivalent skill depending entirely on personal judgment. At present the usefulness of instruments for measuring the temperature of the molten steel is generally accepted. Indicators for fuel flow, roof temperature, furnace pressure and regenerator temperatures are finding increasing acceptance. However, the only satisfactory solution to the problem of open hearth furnace construction will come with the use of improved refractories with melting points further above the working temperature of the furnace and greater resistance to chemical erosion. Several experimental furnaces incorporating basic refractories are now in operation and there seems no reason to doubt that further developments in this direction will follow in the near future.

An important consequence of the greater output of the oil-fired furnace—together with other improvements in productive technique—has been the overall economy in production. Due to the increased tonnage produced, finishing plant has been employed to capacity and the price of steel has decreased relative to the price of most other products.

The rise in output and the increasing difficulty of obtaining raw materials of the highest quality have introduced a number of new problems and aggravated others. One which is worthy of particular mention is the increase in the percentage of residual alloy content in steel made with a high proportion of scrap metal. It is now common to find carbon steels containing 0·20% nickel, 0·20% copper and 0·05% molybdenum. While these elements are not deleterious in the bulk of carbon steel products, for certain applications such as steels for hot piercing, lap welding, etc., they have a harmful effect which presents a major problem.

Unless there is a fundamental change in the economic forces affecting the industry, developments in the next twenty-five years are likely to follow the pattern of the last quarter of a century, that is to say there will be extended application of technical advances which have not been fully exploited. It is, however, probable that the application of the most recent technical developments will proceed at what the research worker at least may regard as an unnecessarily slow pace. The delay in application of ideas will naturally decrease the incentive to develop new processes and products.

It may be predicted that as the economic advantages become apparent and modern design procedures gain wider acceptance there will be a greater demand for improved steels for all types of constructional work. The industry will be able to satisfy such a demand.

Improvements in the quality and uniformity of composition of steel should permit additional reductions in factors of safety in design without increasing the danger of failure. This could be facilitated to a great extent by the rationalisation of steel acceptance tests. It may be anticipated that technical developments will include investigation of the use of tilting open hearth furnaces and duplex processes to compensate for continued deterioration in the quality of raw materials. Experiments with sectional steel moulds to replace cast iron moulds for the production of the larger sizes of ingot will be continued.

We may also hope to see experiments to develop methods for the continuous casting of steel extended as far as the production stage and proving economic for certain products. Another fundamental development to be anticipated would be the introduction of practical methods of quenching plates and sections as they leave the rolls. Such an innovation could solve many problems and by providing higher tensile steels with the most economical use of alloying elements could go far to restore steel to favour with those engineers who have succumbed to the attractions of the competitive non-ferrous alloys.

Steel Castings—Past, Present and Future

By J. F. B. Jackson, B.Sc., A.R.I.C., F.I.M.
Director of Research, British Steel Founders' Association.

At the beginning of the period covered by this review, progress in the production of steel castings had lagged behind the efforts made in the casting of other materials. There was, however, evidence within the industry that the problems of steel casting manufacture presented a challenge to foundry managements and technologists that could not be ignored and by continuous and intensified efforts a level of achievement has now been reached which represents very considerable progress.

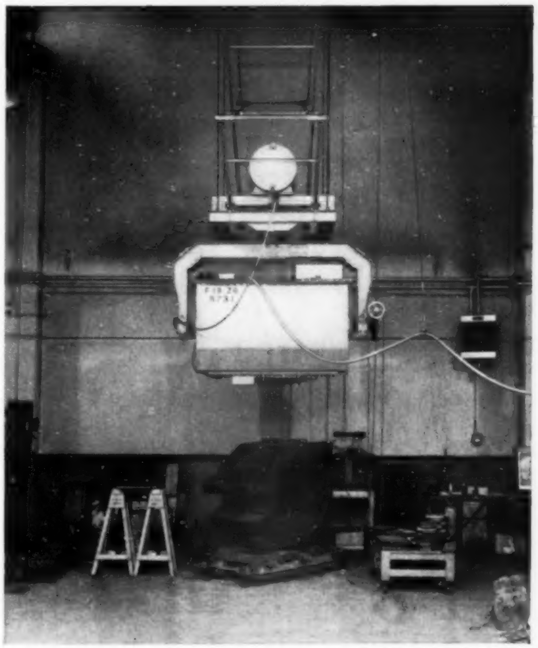
WHILE it is to be expected that all branches of the engineering industry will claim, quite rightly, to have made appreciable progress technologically and otherwise over the past 20 years, and no doubt, over the past 10 in particular, it is unlikely that many will make such a claim with better reason than that section of the foundry industry which produces steel castings.

This statement is in no way intended to infer that the manufacture of steel castings has surpassed all other forms of casting production in efficiency or standards of quality, but rather that an initial lag in these respects, evident 20 years ago, has become decisively something of the past.

There are practical problems inherent in the making of castings in steel that have been responsible for the steel foundry process yielding less slowly to the introduction of scientific method and control. These problems are of course associated with the fact that throughout the manufacturing cycle the steel foundryman is dealing with temperatures of a considerably higher order than is common to the practice of foundries dealing with cast iron or the non-ferrous metals. Steel for castings is usually poured from the ladle at a temperature in the region of 1,600° C., some 250° C. higher than is normal to the iron foundry.

During the 1930's there was, however, marked evidence within the industry of a consciousness that the problems of steel casting manufacture presented a challenge that had jointly to be met, and no longer ignored, by foundry management and technologists, and of a conviction in the minds of the more progressive steel foundrymen that by continuous and intensified effort steel castings could be made to achieve a position of importance among engineering materials such as had never been deserved and accredited to them in the past.

The Reports of the Steel Castings Research Committee of the Iron and Steel Institute, under the chairmanship of Mr. W. J. Dawson, during the 10 years preceding the second world war were perhaps symbolic of this change of attitude toward steel castings manufacture and in a sense marked the advent of the modern steel casting, which like many other material supplies has by no means as yet reached its final level of achievement although it has left very far behind its almost notorious predecessors.



Courtesy of Messrs. Edgar Allen & Co., Ltd.

Fig. 1.—A steel foundry radiographic laboratory equipped with a 400,000 volt X-ray unit in addition to gamma ray sources.

Steelmaking for Castings

Although now much less attractive economically than before the 1939–45 war the Tropenas side-blown converter has, since 1930, received more attention from the point of view of development of steelmaking practice than any other foundry melting unit in the United Kingdom. A previous decline in its popularity, associated chiefly with a dislike for the high sulphur and phosphorus contents of the castings it then produced, was ultimately off-set to a major degree when, during the 1930's, a more complete understanding of both cupola and converter operations and a marked improvement in general standard of practice led to converter steel establishing a much higher reputation for quality than it had hitherto held. Attention to converter refractories simultaneously led to an appreciable extension of lining life and indeed contributed to reproducibility of steel quality.

It is to be regretted that the converter, with all its inherent attractions, e.g., its flexibility in operation, its relatively low capital cost, its frequency of tapping and its high production rate, must under present conditions necessarily bow to the fact that the steel it produces bears such unfavourable economic comparison with other steelmaking processes, including both the electric arc and the high frequency induction. During the war period the side-blown converter made a vital contribution to production and it might well regain its popularity

to some extent should the price and quality of coke appreciably change.

The past 20 years have seen the introduction of a large number of electric arc melting units into the steel foundries, these until relatively lately being operated almost exclusively with basic hearths. In this latter respect rammed dolomite, either dry or tarred, has superseded magnesite without operational complications and with saving in cost. Present emphasis is particularly upon the need for rapid and still more rapid steel melting, both for reasons of productivity and of steel quality. Increase in transformer ratings (up to 600 kVA. per long ton and higher), improved mechanical charging devices, improved electrode controls, the use of acid refractories and the use of the oxygen lance to an extended degree throughout the industry, are obvious future trends.

The so-called oxygen lance, whereby oxygen in gaseous form is fed to the molten bath, has already been established in the United States and to some extent in this country and on the Continent as routine practice, but there remains very considerable scope for its extended use and for appreciation of its potentialities. On the other hand, oxygen enrichment of the Tropenas converter blast, while of course spectacular and interesting, has not been accepted as having any general value for purposes of steel foundry practice.

There has been widespread recognition, regardless of the steelmaking process, of the importance of paying due regard to all factors which can lead to gas absorption during the steelmaking cycle and of taking what hitherto have been regarded as extreme precautions, in particular to avoid the access of hydrogen to the liquid steel and those conditions under which its absorption is liable to occur.

Over the past 20 years the industry has become increasingly conscious of the importance of its steelmaking practice and that this has contributed appreciably to the present status of the steel casting is evidenced by such applications as shown in Fig. 3 and in the material specifications to which steel castings are now available (see Table I).

Mould Refractories

While of late years much has been contributed to our fundamental knowledge of sands and refractories for steel foundry purposes, even more significant perhaps has been the widespread recognition of the need for adequate equipment for the preparation and supply of both mould and core sands to the foundry floor. In conjunction with such equipment the introduction of sand testing units or laboratories for controlling the uniformity of mould and core materials has been extensive throughout the steel foundry industry.

TABLE I.—BRITISH STANDARD SPECIFICATIONS FOR STEEL CASTINGS

B.S. No.	Scope	No. of Grades
592 : 1950	Carbon Steel Castings for General Engineering Purposes	3
1398 : 1947	Carbon-Molybdenum Steel Castings	1
1456 : 1948	$1\frac{1}{2}$% Manganese Steel Castings	2
1457 : 1948	Austenitic Manganese Steel Castings	1
1458 : 1948	Alloy Steel Castings for Structural and General Engineering Purposes	1
1459 : 1948	Alloy Steel Castings for Structural and General Engineering Purposes	1
1461 : 1948	3% Chromium-Molybdenum Steel Castings	1
1462 : 1948	5% Chromium-Molybdenum Steel Castings	1
1463 : 1948	9% Chromium-Molybdenum Steel Castings	1
1617 : 1950	Mild Steel Castings of High Magnetic Permeability ..	2
1630 : 1950	(13% Chromium) Corrosion Resisting Alloy Steel Castings	3
1631 : 1950	(Austenitic Chromium-Nickel) Corrosion Resisting Alloy Steel Castings	2
1632 : 1950	(Austenitic Chromium-Nickel-Molybdenum) Corrosion Resisting Alloy Steel Castings	2
1648 : 1950	Heat-Resisting Alloy Steel Castings	8

Courtesy of Messrs. English Steel Corporation, Ltd.

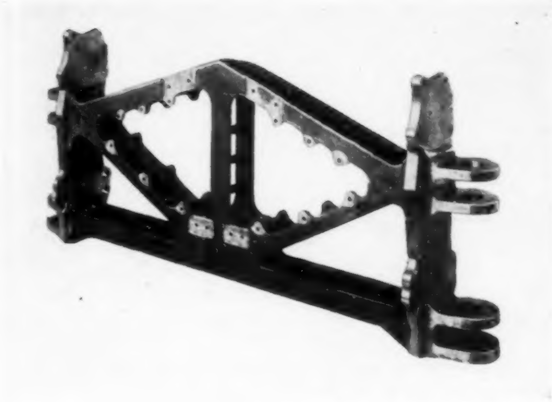
Fig. 2.—Cast steel locomotive bogie frame, 14 ft. long by 6 ft. wide, weight 2 tons.

Particular attention has been paid for a number of years to refractory materials which might act as satisfactory substitutes for silica flour in mould paints and washes, with the object of reducing the health hazard which can arise from this material, but it has at the same time been fully appreciated that unless such substitutes do in fact give cleaner sand-free castings they will almost certainly increase—or lead to an increase—of silica dust concentrations in the atmosphere. As a result of work in this field it has been found possible to employ zircon in place of silica flour in certain classes of casting production and this has been done. Continuous research into the problems associated with the adherence of sand to the surface of steel castings is being conducted by the industry's research organisation, both in the universities and elsewhere. While first importance is thus attached to avoiding the formation of dust, there is similar concentration of effort in developing and applying apparatus for the removal and control of any dust that at present cannot be avoided.

Gating and Heading Practice

It is of course essential to the production of sound steel castings that satisfactory attention be given both to the means by which the molten steel is admitted to the mould cavity and also to the measures which are taken to compensate for liquid shrinkage during the freezing process. Control of gating and feeding procedure is in other words a matter of first-rate importance and present-day appreciation of this is well demonstrated by the number of steel foundry organisations which to-day operate "Methods Departments" not only to record feeding and gating practice which has been established as satisfactory, but also to ensure that such findings are correlated and put to use in connection with new types of castings coming into production.

In addition, there has been marked evidence of interest in, and increasing application of such devices as exothermic moulding materials to induce desired thermal gradients, exothermic compounds for limitation of feeder head volume, the Williams "atmospheric pressure assisted" blind feeder head, feeder head partition cores (i.e., "knock-off" heads or "necked-



Courtesy of Messrs. Hadfields, Ltd.

Fig. 3.—High tensile steel casting for fighter aircraft, replacing heavier assembly of wrought steel components and avoiding excessive bulk of light alloy alternative structure.

down" risers) wherever such devices can be seen to offer advantage.

It is probable that within the next 10 years each of these devices and no doubt others yet to come, will find their real sphere of usefulness in the scheme of foundry practice and each eventually play its part to an extent commensurate with its real value.

Mould and Core Production

The use of moulding machines in the production of steel foundry moulds has of course been accepted practice for many years. Latterly, however, very much more detailed attention has been given to the question of plant layout and of the servicing of moulding machine installations not only with the necessary supplies of prepared moulding sand, but with every facility required for the completion of the moulding operation, with a minimum expenditure of man-power and a minimum departure from standard conditions of mould formation. Productivity and reproducibility of mould quality are in fact jointly the criterion.

Less readily, however, has the use of core-blowing machines and of sand-slingers become general in steel foundry practice in this country, but it may well be that within the early future both these valuable aids to production will be more fully appreciated and put to work.

As stated previously, moulding sand control and the wide use of synthetic sands, employing bentonite clays, have extended appreciably the tonnage and range of steel castings produced in green sand moulds, this in turn reducing the extent to which drying stoves are being installed in the modern steel foundry. Where dry sand properties are regarded as necessary in a steel mould it has been shown that the drying process can satisfactorily be localised and restricted to the surface of the mould which will be in contact with the casting. This has been achieved by the use of specially constructed drying units, which supply relatively large volumes of heated air at low pressure to the mould cavity without the moulding box and the complete bulk of sand it contains being raised above room temperature.

Quite apart from the very considerable saving in the cost of heat necessary for drying moulds in this way, the so-called "unit drying" technique avoids the moving and handling of large moulds, reduces the drying time and virtually eliminates the necessity for capital equipment in the form of drying stoves. The steel foundries of the future may indeed have no mould drying stoves at all, regardless of the type of casting they are producing.

Cleaning Operations

There is full appreciation that the extent to which cleaning operations, i.e., shotblasting, grinding and dressing with the pneumatic chisel, are necessary, is measured very largely by the degree of efficiency with which the preceding stages of manufacture are performed. The majority of research projects upon operational aspects of the steel castings process have an ultimate bearing, therefore, upon cleaning and fettling and, therefore, upon conditions affecting the operator.

The introduction, where practicable, of the "Hydroblast" principle for the preliminary stripping of the mould from the casting has without any doubt appreciably reduced dust formation at this particular stage in manufacture. The use of automatically and externally operated airless shot-blast devices have similarly found wide application of late years and these too have contributed to an improvement in atmospheric conditions within the foundry.

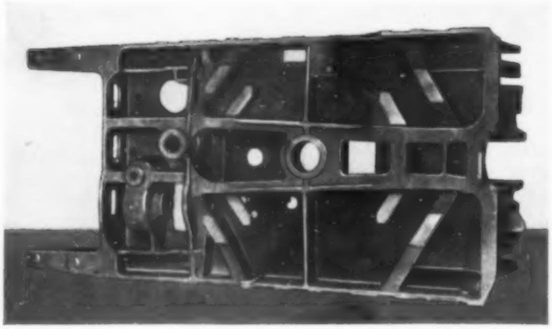
The industry as a whole is very much alive to the importance of taking all measures possible to avoid dust formation and is actively engaged in research and practical development with this object solely in view. To meet circumstances under which dust prevention cannot immediately be achieved, steps are taken to meet the problem by precautionary measures, such as the new-type respiratory mask, recently developed by the British Steel Founders' Association, which not only provides efficient filtration but maximum comfort to the wearer.

There is also in operation within the industry a scheme, also sponsored by the British Steel Founders' Association, for regular full-plate radiographic examination of operators who may be exposed to health hazard through dust and there is considerable hope for the success of this scheme in the future.

Non-Destructive Testing

Previous to 1940 not more than 5% of the steel foundries in this country made regular use of radiography as an inspection method. The extent to which electro-magnetic and other forms of surface flaw detection were employed is not known precisely but it is probable that the same figure would apply.

There is no doubt that the high installation cost of X-ray equipment originally deterred many steel founders from its use, although those that were sufficiently far-sighted and enterprising in this direction were quick to see the return for their outlay. Recognition, however, of the practical value of radium, and later of radon, gave considerable impetus to radiography generally and by 1950 some 20% of British steel foundries either had their own facilities or made frequent use of available services. The availability of radio-active isotopes, for immediate purposes particularly iridium 192 and tantalum 182, will undoubtedly serve further to popu-



Courtesy of Messrs. F. H. Lloyd & Co., Ltd.

Fig. 4.—Cast Steel revolving frame for excavator, length 14 ft., weight 5 tons.

larise radiography as one of the most valuable and easily applied tools in the hands of foundrymen.

It should be stressed that in steel foundry practice the routine application of radiography is normally in the proof of feeding and gating technique by the examination of sample or pilot castings prior to bulk production being put in hand. It is of course also applied as a final inspection procedure upon castings required for particularly highly stressed service applications.

Applications and Specifications

Figs. 2, 3 and 4 illustrate three steel casting applications of engineering interest and these taken in conjunction with Table I, which lists available British Standard Specifications, provide an indication of the wide range of properties given by present-day carbon and alloy steel castings.

It is noteworthy that the modern steel casting specification makes reference to the application of non-destructive testing, particularly stressing the importance of acceptance standards being agreed between designer and producer at an early stage. Specifications apart, it is well recognised to-day that the closest possible collaboration between the design engineer and the steel founder should be fostered in all cases where castings of any appreciable size or importance are concerned. The more exacting the intended service conditions the more urgent it is that discussion upon design between these two directly interested parties should take place. While there is noticeably less reluctance and in fact real evidence of enthusiasm in many cases upon the engineer's part these days to discuss his requirements with the steelfounder, the latter still tends to accept without demur designs which are quite unsuitable for casting and for production and even to accept such requirements as a challenge to his ingenuity. This attitude is harmful to both the producer and the user and the future will no doubt see it disappear.

Co-operative Research Within the Industry

Towards the latter part of the 1939–45 war period the industry became increasingly aware of the need for the establishment of its own research organisation, which, during 1949, appeared as the Research and Development Division of the British Steel Founders' Association, with headquarters in Sheffield.

This research organisation has, of course, its own permanent staff and, in common with similar research bodies of relatively recent origin, makes use primarily of existing laboratory facilities attached to the universities and industrial concerns within the industry. Its policy is such that, while fundamental research projects are as a matter of course sponsored for the long-term benefit of the industry, major importance is at all times attached to the translation of the results of research and development into immediate practice. The permanent staff have at all times the benefit of the advice of a small number of technical standing committees, manned solely by experts from within the industry. The organisation has already given further proof, if this were needed, of the importance of co-operative research in the structure of modern industry.

World Iron and Steel Resources and their Utilisation

THE basic resources needed for an iron and steel industry are available and can be assembled economically in a number of localities in each of the major under-developed areas throughout the world. This is one of the conclusions, supported in detail by a comparative analysis of the resources available and the transportation requirements for the production of steel and for the delivery of steel to markets in under-developed areas, in a report* on the above subject. The report is the first of a series of studies, prepared by the Economic Stability and Development Division of the Economic Affairs Department, following a resolution of the Economic and Social Council which emphasised the need for facilitating the better utilisation of world resources of man-power, materials, labour, and capital in order to promote higher standards of living throughout the world, more particularly in undeveloped and under-developed areas.

The findings of the report indicate that iron ore with a metallic content and of a quality comparable with, or better than, those now commercially exploited in the industrialised countries, are available in large quantities in under-developed regions. The known ore reserves in the more populated of these areas are adequate to support a large iron and steel industry, while many of the smaller under-developed areas have iron ore deposits suitable for economical mining.

Lack of sufficient good quality coking coal presents a serious problem in connection with the development of steel production in many of these areas, two-way trade in iron ores and coking coals would, therefore, assist steel development and increase the steel-making potential throughout these under-developed areas. The present limited demand for iron and steel in under-developed countries is a retarding influence on the establishment of steel industries in these countries, but this difficulty can be overcome by progress in diversified economic development.

Although the quantity, quality and location of existing resources and markets are advantageous for establishing or expanding a steel industry in a number of under-developed countries, it is probable that iron and steel production initially will not be as efficient in the under-developed countries as it is now in the industrialised countries. As a consequence, the new steel industries in under-developed countries will probably need some kind of protective measures.

* Published by the United Nations Secretariat; copies of which will shortly be available from H.M. Stationery Office or from booksellers.

A Review of the Developments in the Metallurgy of Cast Iron

By J. E. Hurst, D.Met., F.I.M.

The period of this review has witnessed developments in cast irons and their uses that are truly remarkable. They have been concerned with improved foundry technique in the production of sound castings, high strength cast irons and alloy cast irons having improved characteristics in various aspects of the mechanical properties, and have raised the metallurgy of cast iron to a level ranking in importance as high as that of steel and the major non-ferrous metals and alloys.

As far back as August, 1909, at the Birmingham Conference of the British Foundrymen's Association, Professor Turner reviewed this same subject in an address entitled "Twenty-five years of Cast Iron." Almost half a century has elapsed since this address, but one sentence in it that "the renewed and extended interest in cast iron came as a surprise to those who believed the days of the ironfounders were numbered, and was a revival which was as unexpected as it was pronounced" might still be used with fitness in reviewing this subject over the period 1929 to date, the "coming of age" of METALLURGIA. This period has witnessed developments in cast irons and their uses which may be truly described as remarkable. At the same time the developments in other materials and processes, the light alloys, plastics and fabricated structures for example, have been such that some might have been led to believe the days of the ironfounder to be numbered. This competition in itself, has played a very great part in the developments and extended uses of cast iron. During the period under review these developments have been concerned with improved foundry technique in the production of sound castings, high strength cast irons and alloy cast irons having improved characteristics in various aspects of the mechanical properties such as modulus of elasticity, fatigue resistance, damping characteristics, hardness and wear resistance, heat and corrosion resistance, and electrical and magnetic properties. It is specially interesting to reflect that in addition to extending the boundaries of the ironfounding industry all these developments have done much to raise the metallurgy of cast iron to a level ranking no less in importance than that of steel and the major non-ferrous metals and alloys.

Nodular Cast Irons

The development of nodular cast irons is the outcome of many years of continuous research on the subject of graphite formation by the British Cast Iron Research Association. It is a development which overshadows all others in this field of metallurgy, and this work associated particularly with the patient, arduous and elegant work of Morrogh and his collaborators at the Association must be acknowledged as classical both in its conception and execution. This, of course, does not detract in any way from the work of the International Nickel Company and the Associated Research Laboratories in this same field of activity.

It is well known that ordinary grey cast iron contains graphite or free carbon distributed through the metal essentially in the form of flakes or lamellæ. The relative brittleness and absence of ductility of ordinary cast iron is in a large measure due to the presence of this flake-like form and distribution of the graphite. In malleable cast iron, produced by the heat treatment of white cast iron according to the conventional malleabilising process, the free carbon exists in the form of nodules. These temper carbon nodules as they are often referred to consist of spheroidal aggregates of graphite, and in this form do not exert such a deleterious influence on the mechanical properties as the flake-like form. These facts are well known, and it has always been obvious that if cast iron could ever be produced with the graphite in the nodular form an improvement in the mechanical properties would result. Hitherto the nodular form of graphite has been produced only in the malleable cast irons by subjecting white irons to a subsequent heat treatment process following upon solidification.

The methods developed by the British Cast Iron Research Association and the Mond Nickel Company in this country enables nodular graphite structures to be produced in cast irons without the necessity for applying heat treatment as in the malleable cast iron process, and cast irons produced by these respective processes are now spoken of as nodular cast iron.

Gaseous Annealing Processes for the Production of Malleable Cast Iron

Reference to the developments in the production of nodular cast iron almost automatically directs attention to the improvements in the old established processes for the production of malleable castings. Developed during the war years, the process of gaseous annealing has now become a practical system for the annealing of whiteheart malleable castings. In this field the work of Robiette (Proc. I.B.F. 1944–45) and Jenkins and his collaborators (Proc. I.B.F. 1944–45–46) is specially noteworthy. The essential features of this process lie in the controlled decarburisation of the white iron castings by annealing in a gaseous atmosphere of controlled composition. The most readily available sources of such gas mixtures are produced by the partial combustion of fuel gases such as Town's gas, producer gas or carburetted water gas. Under these conditions the packing of the castings in containers and with hematite ore can be dispensed with, and with suitably designed furnace plant thorough malleabilisation is effected in relatively short cycles. Utilising electric furnaces and automatic gas control the whole process can be rendered fully automatic and indeed, if the type or production warrants it, and the cycle is a regular one, a programme controller can be installed. A predetermined heating,

soaking and cooling cycle is drawn as a curve, and the instrument will control the whole process to this actual cycle, thus bringing the whiteheart malleable process truly into the category of precision operations.

High Duty Cast Iron

The science and technology of cast iron has progressed at a very rapid rate during the last decade. The strength of cast iron is one property which has reflected this progress. In 1927 the first British Standard Specification for Cast Iron, B.S.S. 321, recognised only two grades of engineering iron of tensile strength 9 tons per sq. in. and 12 tons per sq. in. The latest specification, B.S.S. 1452 (1948), refers to seven grades ranging in tensile strength from 11 tons per sq. in. to 28 tons per sq. in. A recent development since the publication of this last specification has produced an iron of 35 tons per sq. in.

In the first report of the High Duty Cast Iron Committee of the Institution of Mechanical Engineers, dated December, 1938, a list of high duty cast irons in general production was compiled. This list, which covered those cast irons developed specially for their high-strength properties, included those made from mixtures containing a high percentage of steel or refined iron; cast irons made in special furnaces, air furnaces, rotary and electric furnaces; alloy cast irons in which the elements nickel, chromium, molybdenum and copper are used principally; heat-treated cast irons and cast irons of Ni–Tensyl and Meehanite types.

TABLE I.—TYPICAL COMPOSITIONS AND PROPERTIES OF NON-ALLOY CAST IRON.

No.	Composition %					Mechanical Properties		Type of Iron
	T.C.	Si	S	P	Mn	Tensile Strength tons/ sq. in.	Brinell Hardness	
1	3·20	2·50	0·09	0·90	0·70	10·0	205	Grey iron for concentrated sulphuric acid pot, 8 in. diameter 6 ft. deep.
2	3·00	1·80	0·06	0·20	0·80	18·0	220	High duty cast iron for pump bodies, etc.
3	3·60	1·50	0·06	0·04	0·75	14·0	180	Hematite base iron for soda pots.
4	3·20	1·80	0·09	1·00	0·65	15·0	185	Cast iron pipe (sand spun).
5	3·00	0·50	0·15	0·40	0·90	15·0	500	White iron for wear resistance.
6	0·60	0·70	0·15	0·15	0·35	20·0	180	White heart malleable.
7	2·80	0·70	0·15	0·10	0·50	22·0	160	Black heart malleable.

The compositions and mechanical properties of various types of grey cast iron are given in Table I. The exact composition of an iron depends to some extent upon the section size of the casting. To preserve a soft machinable grey iron the carbon and silicon percentages must be carefully balanced. Most grey iron has a microstructure showing a matrix of pearlite.

An important development in this field of High Duty Cast Irons during the period under review is that of the manufacture and use of alloy additions.

The main effect of alloy additions to cast iron is in general to reduce the effect of section size and to give a more homogeneous structure with a corresponding increase in the physical properties. Nickel, copper, chromium, molybdenum, and vanadium, either singly or to a greater extent when in combination, are used for this purpose. The disadvantage of chromium by itself is that it is a carbide-former and it tends to give white iron. When chromium is used in conjunction with nickel or copper in the proportion of two or three parts of nickel or copper to one part of chromium, the tensile

TABLE II*.—LOW ALLOY CAST IRONS.

No.	Description of Iron	Composition %					Mechanical Properties	
		T.C.	Si	Mn	Ni	Cr	Tensile Strength tons/ sq. in.	Brinell Hardness
1	Nickel cast iron for light sections	3·3	1·8	0·7	1·5	—	18	220
2	Nickel cast iron for medium sections.. ..	3·2	1·2	0·7	1·25	—	18	210
3	Nickel–chromium cast iron for medium sections	3·2	1·6	0·7	1·25	0·5	18	220
4	Nickel–chromium cast iron for heavy sections	3·2	1·0	0·7	1·25	0·5	18	200
		For machinability, density, strength and wearing quality						
5	Nickel–chromium cast iron	3·2	1·2	0·8	1·0	1·0	17	250
		For heat resistance						
6	Ni-tensyl	2·9	1·5	0·8	1·5	—	22	220
7	Hard grey iron	3·3	1·2	0·8	3·0	0·5	20	300
		For maximum wearing quality and machinability without heat-treatment						
8	Heat-treatable cast iron for light sections ..	3·3	1·6	0·7	2·0	—	25	350
9	Heat-treatable cast iron for heavy sections ..	3·2	1·4	0·7	2·5	0·5	25	300
		For wearing quality and strength after heat-treatment						
10	Acicular iron for high-strength engineering purposes	2·9	2·0	1·0	3·5	Mo 1·0	24–25	300
11	Special iron for high pressure pumps	2·9	1·70	0·5	0·7	0·5 Mo = 0·8	25–28	260

* Courtesy of Mond Nickel Company.

strength is markedly improved and the cast iron becomes more susceptible to heat treatment. Low alloy iron may be heat treated in much the same way as steel to give an almost unlimited range of physical and mechanical properties.

Low alloy cast iron is stronger at elevated temperatures and is less susceptible to growth due to heat.

Some typical alloy irons are given in Table II. Item 11 in Table II is an iron very suitable for pressure castings and high-pressure centrifugal pump castings. It has a tensile strength of 25 to 28 tons per sq. in.

Martensitic Irons

An alloy addition of 4% to 5% of nickel, 1% to 1·5% of chromium, causes an iron to lose its easy machining properties and it becomes hard and unmachinable. It has a microstructure showing carbides and martensite, a hard needle-like constituent similar to that found in heat-treated tool steel. Martensitic irons are abrasion-resisting irons of considerable importance for crushing and grinding plant of all descriptions. Their superior abrasion resistance is outstanding, especially when applied to ball mill liner plates, air-less shot blast blades, clay-handling machinery, grinding pans, gravel pipes, etc.

TABLE III.—ABRASION RESISTING IRONS.

No.	Composition %						Mechanical Properties		Type of Iron
	T.C.	Si	Mn	Ni	Cr	Mo	Tensile Strength tons/ sq. in.	Brinell Hardness	
1	3·5	0·8	0·4	2·5	1·5	—	20	650	
2	2·9	0·5	0·4	5·0	2·0	—	20	600	Typical Ni-hard
3	2·9	0·5	0·4	3·0	1·5	1·5	20	600	
4	2·5	0·7	0·4	4·5	1·5	—	20	650	B.F.954
5	2·0	1·7	1·0	—	32	—	30	320	High-chromium
6	2·6	1·1	1·0	—	19	4·0	22	600	Chrome-molybdenum

The composition and mechanical properties of some typical members of this group of martensitic irons are shown in Table III, items 1 to 4.

High Chromium Irons

Cementite or iron carbide is not the only carbide which confers upon cast iron a resistance to abrasion Chromium and tungsten, in common with iron, readily forms carbides which are hard and resistant to wear, impact, abrasion, etc. Chromium in relatively large amounts (5% to 30%) forms a complex iron carbide. An abrasion-resistant alloy worthy of comment is the high chromium cast iron containing 30% of chromium. This alloy iron possesses, in addition to good abrasion-resisting properties, an extremely good heat resistance. It has, therefore, an application to positions where both scaling by heat and abrasion are serious considerations. The carbon content of the iron may be adjusted to obtain the desirable degree of hardness and toughness. The carbon must not be too high or the metal becomes brittle nor yet too low or the metal will not be sufficiently hard. A typical composition is given in Table III, item 5.

Casting stresses in the high-carbon alloy may be relieved by heat treatment so as to obtain the maximum toughness. An improvement in the strength and abrasion resistance may be secured by including nitrogen in the composition. It is rather interesting that 0·5% of nitrogen behaves as an alloying metal with a toughening and hardening influence upon the high chromium iron.

An alternative abrasion-resistant high-chromium iron in which some of the chromium is replaced by molybdenum is shown in Table III, item 6. This chrome-molybdenum iron is a tough hard material very suited to abrasion conditions where some impact resistance is also required. A small addition of boron is usually made to the alloy to secure the development of maximum mechanical properties.

Acicular Irons

A recent development in high duty engineering irons is the so-called acicular iron, of typical composition shown in Table II, item 10. The precise composition is varied to suit the section size. In the as-cast condition, the iron has a strength of 25 tons per sq. in. and Brinell hardness of 300. Upon simple annealing treatment at 315° C. for 5 hours, the tensile strength may be increased to 45 tons per sq. in. Its resistance to shock and impact loading is well in excess of that of the best quality grey iron and most low alloy irons. It is used with considerable success for crankshafts.

Nodular Cast Iron

Another very recent development which might be of considerable importance in the ironfounding industry is nodular cast iron. As its name indicates, the graphite in this iron is in the nodular form in the as-cast condition. In this form the graphite has less weakening influences on the cast iron. The basis of the process is that when small quantities (0·1% to 0·2%) of cerium or magnesium are added in the ladle to an iron of correct composition, it solidifies with the graphite present in the nodular form. Strength of up to 45 tons per sq. in. with an elongation of 1% to 3% have been obtained. After a six hour anneal at 700° C. the iron, whilst retaining the high tensile strength of 35 tons per sq. in. has also an elongation of 16%. A typical analysis is given in Table IV, item 1.

Considerable research is being conducted at present to find the best condition under which this iron can be most usefully employed. There is little doubt, however, that its strength and toughness will be valuable for the manufacture of many castings in the engineering industry. Whilst at the moment the best results are obtained with the iron of composition given in Table IV, item 1, world-wide research is seeking to extend its applicability to other compositions, especially with high-phosphorus irons. A search is also being made for other nodularising agents in addition to cerium and magnesium.

TABLE IV.—SPECIAL PURPOSE CAST IRONS.

No.	Composition %							Mechanical Properties		Type of Iron
	T.C.	Si	S	P	Mn	Ni	Cr	Tensile Strength tons/ sq. in.	Brinell Hard-ness	
1	3·40	2·50	0·015	0·10	0·5	Mg or Ce	—	40	200	Nodular iron
2	2·20	6·00	0·05	0·05	0·5	—	—	15	220	Silal
3	2·00	6·00	0·04	0·05	0·6	18	2·0	14	120	Nicro-silal
4	3·00	2·20	low	low	1·2	15 Cu = 6	2·0	20	160	Ni-resist
5	0·50	14·5	0·04	0·15	0·6	—	—	10	450	Acid resisting silicon iron

Heat-Resisting Irons

Resistance to the action of heat is a property of great value in the chemical industry. Ordinary phosphoric grey iron has little heat resistance above 500° C. At higher temperatures it suffers in a marked degree from oxidation or scaling which causes growth, giving an actual increase in dimensions. Hematite irons have a greater heat resistance and have been used successfully for some applications up to 800° C. White irons, especially those with low carbon and low silicon and with the addition of a carbide stabiliser such as chromium up to 2%, have good heat-resisting properties.

Breakdown under heat of the carbides in iron causes the deposition of graphite which may result in volume changes with increases in size up to 2%. Oxidation of the ferrous material itself will cause further volume increases. The casting may eventually become honeycombed with cracks. Attack of the oxidising gases may also result by penetration along graphite planes and, in general, irons with fine graphite have good scaling resistance. Several types of iron have been developed to resist oxidation at high temperatures. Silal and Nicro–Silal are two irons developed by the British Cast Iron Research Association especially for the purpose of heat resistance. Both these irons have a good scaling resistance up to a temperature of 800° C. in air and furnace gases, and the latter is valuable in sulphurous atmospheres. The compositions of these irons are given in Table IV, items 2 and 3.

Silicon raises the temperature of the pearlitic change point and with 6% of silicon this critical point is raised to approximately 900° C. Thus, provided Silal is used below this temperature, no volume changes due to phase changes take place and hence the iron has little opportunity for heat crazing and further growth due to oxidation. A correctly made Silal casting should consist structurally of a silico-ferrite matrix and fine eutectic graphite.

Owing to the somewhat brittle nature of Silal and its low resistance to thermal shock, its sister alloy, Nicro–Silal, was developed. This iron is austenitic in character, which means that the critical change point is depressed

TABLE V*.—DATA ON HEAT RESISTANCE OF CAST IRON.

	Temperature at which serious scaling and growth take place	Maximum temperature for practical use
Ordinary cast iron	500° C.	450° C.
Pearlitic cast iron	650° C.	550° C.
1% chrome cast iron	750° C.	600° C.
Silal 4–10% silicon	900° C.	750° C.
Nicro-Silal	—	—
Ni-resist and similar high-Ni-Cr irons including high-chromium irons	No change up to 900° C.	950° C.

* Inglis, "Some notes on heat-resisting metals," Society of Glass Technology, 1933.

below atmospheric temperature. It is tougher and more ductile than Silal and resists scaling up to a temperature of 950° C. Another highly alloyed iron, Ni–Resist, to which reference is made later, is also useful for high-temperature scaling resistance. The high-chromium irons, to which reference has already been made in connection with their abrasion resistance, may be used successfully in scaling atmospheres up to a temperature of 1,100° C. They are particularly valuable in the presence of sulphurous gases. All these irons retain a considerable degree of tensile strength at high temperature. They also retain their rigidity under the influence of heat to a marked degree as compared with steel and ordinary cast iron.

The data given in Table V indicates the relative value of some of the cast irons in common use in places where heat resistance is desirable.

Corrosion-Resisting Irons

Resistance to acid corrosion is not an outstanding property of ordinary grey irons, although under certain conditions it may be quite good. It is a material, however, which by various surface treatments can be made to give good service in the chemical industry. Examples are, protective coatings of nickel, chromium, zinc, cadmium, and lead. Cast iron is very well adapted for vitrous enamelling with acid-resisting enamels. It is sometimes protected with bitumastic coatings and concrete linings.

Special types of cast iron can be nitrogen-hardened to give a higher surface hardness, which also has quite a good resistance to corrosion; these irons contain chromium and aluminium. Nitrided iron is extensively used for cylinder liners.

Some cast irons containing alloying elements have been developed especially for corrosion resistance, and Nicro–Silal and Ni–Resist are two examples. Typical compositions are given in Table IV, items 3 and 4. These austenitic irons have good resistance to the action of weak acids, alkalis, and many types of corrosive salts. They also withstand shock and corrosion fatigue. The impact resistance is stated to be between three and eight times that of ordinary grey iron. They are much improved in strength and ductility by the nodularising process to which reference has previously been made.

In the iron-chromium series of cast irons, resistance to corrosion can be obtained in almost direct relation to the chromium content and inversely proportional to the carbon content, which for a plain corrosion-resisting iron should not exceed 0·2%, whereas with 20% to 35% of chromium a satisfactory alloy may contain 1% to 3% of carbon. These alloys are used under conditions where corrosion and abrasion are serious considerations.

The Formulation of Anti-corrosive Compositions For Ships' Bottoms and Underwater Service on Steel

First report of Joint Technical Panel N/P2—Paints for Underwater Service in Steel.

11 in. × 9½ in., paper cover. 26 pp., 19 illustrations. Obtainable from the British Iron and Steel Research Association, 11 Park Lane, London, W.1. (free of charge.)

This report gives the detailed results of tests made on 68 specially formulated anti-corrosive compositions. The principal aims were a study of the effect of changes in the medium and an investigation into the influence of small changes in pigmentation on the protective properties of two of the best compositions from earlier experimental work, which (coded as formulations Nos. 175 and 185) have found wide acceptance in both naval and mercantile practice.

The 68 compositions comprise systematic variations of mixtures of basic lead sulphate, white lead, aluminium powder, Burntisland red and barytes. All pigmentations have been duplicated in compositions bound, respectively, with a modified phenolformaldehyde stand oil medium and a coumarone/stand oil medium In addition, three of the pigmentations have been bound with each of five other media including chlorinated rubber and media derived from the modified phenol-formaldehyde/stand oil by the substitution of dehydrated castor oil or tung oil for part of the stand oil.

Two coats of the anti-corrosive compositions under test were applied to the specimens and in each case the painting system was completed with a final coat of an anti-fouling composition to an agreed formulation, which was the same throughout. Two types of test were applied: raft trials under conditions of complete immersion at Caernarvon and Emsworth, and accelerated laboratory tests using the C.R.L. high-speed rotor.

Eight of the compositions are placed in the "very good" group, all of which appear to be improvements even upon the earlier formulations. The best performances were given by paints bound in chlorinated rubber, which confirms earlier raft tests at Caernarvon.

The effect of pigmentation was slight, but the tendency was for an increase in the aluminium content to result in improved performance, as regards both protective properties and can stability. Three compositions in which Burntisland red was replaced by a natural red oxide gave better results than the compositions from which they were derived, but further work is required before advocating this change.

From considerations of performance and general applicability the most promising composition studied in this programme is composition No. 655. This has a pigmentation of 2 parts of basic lead sulphate with 1 part of each of aluminium powder, barytes and Burntisland red bound in a modified phenol-formaldehyde/stand oil/tung oil (ratio of oils 1 : 1) medium. This composition has been selected for use in comparison with No. 185 containing the same pigmentation in the plain modified phenol-formaldehyde/stand oil medium in a new service test about to be conducted by the Panel.

The report includes a short statement of the various service tests on bottom compositions that have been executed to date.

Twenty-One Years Progress in Refractories

By J. H. Chesters,* D.Sc.Tech.

The refractories manufacturer and the furnace builder have been remarkably successful in recent years in meeting increasingly severe requirements of the consuming industries, as is shown by laboratory test data and service results, but it is still true that refractories are a limiting factor in furnace design and operation.

THE user of refractories quite naturally looks upon new developments as a response to the demands made by him. There is no doubt that the emotional urge to produce a better brick often arises from such demands, but it is equally true that the manufacturer is continually striving to improve his product by the study of raw materials and manufacturing methods. In the present review an attempt will be made to see what the manufacturer has been able to do in recent years to meet the increasingly severe requirements of the consuming industries. That he has been remarkably successful is shown both by laboratory test data and service results.

Some of the service improvements are due to factors other than refractory quality. Thus the life of silica bricks in open-hearth furnace roofs has been increased by attention to heating-up schedules and by the use of roof pyrometers. Further, such engineering developments as suspended brickwork, interlocking shapes, and water-cooling, have enabled furnaces to be kept in operation long after they would otherwise have failed.

Raw Materials

The first open-hearth roofs to satisfy Siemens were apparently made from Welsh quartzite. A large proportion, however, of the roofs made since then were of ganister, such as occurs in the Sheffield and North-East coast regions. There is little doubt that this is an easier material for brickmaking, but it is not available in the quantities now required. Excellent bricks are now made from a variety of quartzites of the more coarsely crystalline type, but even these rocks are limited in supply and attention is being concentrated on their economic use, and in particular on the possibility of producing super-duty bricks from specially selected material of unusually low flux content. To be suitable the rock must also yield a brick of high bulk density.

The dolomite supplied to the metallurgical industry has always been relatively pure, but there has recently been considerable tightening of control over raw materials both as regards chemical composition and texture. For certain purposes better results are obtained with magnesite, such as has been mined since before the turn of the present century in Austria and Greece, and more recently in a number of other countries, such as Manchuria.

Probably the most remarkable development in refractory materials during the period under consideration, is the sea-water magnesia process. Numerous attempts had been made to obtain refractory magnesia from dolomite and limited attempts to obtain magnesia from the sea, e.g., Marine Chemicals produced magnesium hydroxide for pharmaceutical purposes, but the process now employed in this country and in the United States achieves both objectives simultaneously, the sea-water being reacted with slaked calcined dolomite to give a magnesium hydroxide precipitate. This process not only provides magnesia in countries where no magnesite is available, but opens two new possibilities: firstly, the raw material can be produced with any desired purity, and, secondly, additions can be made to the hydroxide slurry prior to firing and extremely even distribution obtained in the clinker. In the early stages of this development there was considerable doubt whether refractories produced from sea-water would have properties similar to those of refractories made from natural magnesites. It can now be stated on the basis of numerous laboratory and works tests that sea-water magnesia meets all requirements.

It is a peculiar fact that chrome-ore is mostly produced in countries which do not consume it. The necessity of using chrome ores from new sources and the desirability of using those capable of giving the best service, led to considerable fundamental research by the British Ceramic Research Association during the late war. This work enables a choice to be made of chrome-ores for special purposes, e.g., all-basic furnace roofs, on the basis of fundamental knowledge of the chrome spinel minerals and of the reactions of these minerals with iron-oxide. It is even possible that the chrome-oxide-containing brick of the future will be a synthetic product, designed to resist iron-oxide bursting to a degree at present unknown.

The clays used to-day are similar to those employed fifty years ago. Other special materials, e.g. china-clay, are used to a limited extent. They were of course employed even in the early days for the production of steel melting crucibles, but are now being applied in such widely different fields as high-temperature insulation and blast furnace stack linings. In the United States considerable advantage has been taken of the Missouri diaspores to produce a range of super-duty bricks, starting from 42% alumina. In Great Britain recourse has been made to imported minerals, such as sillimanite, kyanite and andalusite. All these latter minerals are of the $Al_2O_3.SiO_2$ type, and form an excellent basis for special refractories of high volume stability, e.g., burner blocks. For the very high alumina grades use is frequently made of calcined or electrically fused bauxite.

Of the other materials now being employed, mention should be made of olivine ($(Mg,Fe)_2 SiO_4$) and serpentine ($3MgO.2SiO_2.2H_2O$), both of which are used in the production of forsterite bricks. Most of the olivine for this purpose has come from Norway, though dunites from the Carolinas have also been used. Serpentine is also employed as a major constituent in the production of stabilised dolomite bricks.

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Pretreatment

The washing of china-clay is a process that has been in use for thousands of years. It differs from tempering in that the objective is to remove undesirable impurities, such as felspar and quartz, rather than increase plasticity. More recently, washing has been widely adopted for the cleaning of silica rock and sand for open-hearth furnace work. Quartzites as mined are frequently contaminated with over-burden, much of which can be removed by high-pressure washing with a drop in the alumina content of the order of 0·2%. Far bigger improvements are obtained with sand, the final product having an alumina content of only a fraction of 1%, compared with several percent in the crude material.

In view of the critical effect of alumina on the refractoriness of silica, these developments are far more important than the percentage purification suggests. The removal of gangue material from chrome ores by tabling or flotation has also been suggested, but is rarely employed. The most that is normally done is to select ores according to the use to which they are to be put. In Great Britain priority is at present given to chrome-ore required for all-basic furnace roofs.

Certain materials, e.g., clay, are often subjected to a prefiring treatment. The bulk of prefired grog in the ordinary fireclay brick consists of kiln waste, but in certain plants lump clay is calcined either in shaft kilns or rotary kilns to give a controlled product for mixing with the plastic raw material. China-clay bricks consist largely of such precalcined grog, since otherwise their shrinkage both in firing and use would be excessive. Sillimanite and kyanite are also normally calcined prior to use, in order to reduce firing expansion and facilitate grinding. Some firms precalcine chrome-ore, but it is doubtful whether the advantages offset the costs. For certain purposes, e.g., cements, serpentine rock is used in the raw, but for brick production the rock is normally calcined.

Grinding and Grading

Even a casual observer would notice a vast improvement in the engineering equipment of the modern brickworks compared with its counterpart of twenty-one years ago. In the early days the batch was thrown into a mill, usually of the solid bottom pan type, and ground until it felt right when squeezed in the hand. At this stage it was considered acceptable to the moulders regardless of its precise grading. The realisation that this procedure was far from scientific, led to a general movement towards grinding, sieving and remixing. In this way products of known grading could be produced and controlled variations made for special products. This was a big step, although in certain instances it may have been a retrograde one, in that controlled pan milling frequently leads to a denser product than can be obtained by sieving and remixing. The reason is subtle, but appears to be connected with the shape as distinct from the size of the individual particles.

Even so where grading control is vital, e.g., in the production of special chrome-magnesite bricks, or of induction furnace linings, it may be better to sieve and remix to give a standard grading and, therefore, a definite packing density or thermal shock resistance. Certain of the earlier work on the effect of grading of silica bricks showed that the best results were obtained with what was known as (45–10–45) coarse–medium–fine type grading, where the sieve fractions could, for example, be 7–25, 25–72, and through 72 B.S.I. sieves. Later experience with induction furnaces showed that it was desirable to divide the through 72 mesh section into two sub-sections, viz. : 72–150 and through 150 mesh, since a fine fraction consisting entirely of 72–150 mesh sinters poorly, while one consisting solely of through 150 mesh material is difficult to ram, particularly if the material is dry. A convenient sub-division for induction furnaces was found to be :—

B.S. Sieve	Percentage
7–25	45
25–72	10
72–150	20
Through 150	25

Where new refractories are being developed the above grading offers a convenient starting point, the porosity with most refractories being of the order of 20% compared with, say, 30% for an uncontrolled batch.

Mixing

Where batches consist of a large amount of one material, say silica, with a small amount of another material, say 2% of lime, it is essential that the minor fraction be well distributed. This can be done by grinding it with the initial batch, but where the grading has already been prepared further grinding may destroy it and some efficient type of paddle mixer is, therefore, employed. In one very popular type the stirring action of the paddles is combined with a gentle kneading action of raised rollers.

Another procedure now frequently combined with mixing is de-airing, although this is normally limited to fireclay products. It was shown roughly twenty years ago that fireclay extruded as worms into a chamber of moderate vacuum and subsequently repugged was extraordinarily strong, in the green, dried and fired states. For example a fireclay pipe could be slit from end to end and then rolled up like a stair carpet without even cracking. This discovery, which has been widely applied, is valuable to the manufacturer, as it enables him to reduce waste and work the clay in a manner that would hitherto have been quite impracticable. De-airing is also a gain for the user, since the density of de-aired products, e.g., casting-pit refractories, is appreciably greater, and the permeability markedly lower due to the closure of interconnecting pores.

Moulding

For a long while it was considered that the only satisfactory method of moulding bricks was that employed by the Egyptians, in which lumps of material were thrown into a mould, tamped with a hand-rammer and then slicked-off. Such a process, although still used for complex shapes, does not yield a standard product. Every moulder has his own technique and indeed no two bricks are likely to be similar, either in density or location of moulding faults. One of the first attempts to overcome this was the use of pneumatic rammers, which have been widely used with hand moulds for the production of silica and basic brick batches. More recently these have been partially replaced by bumping presses which are particularly useful for the manufacture of special shapes. The latest tendency is to change over to high-powered presses, either of the mechanical (toggle) or hydraulic type. The mechanical presses normally yield a big output, being capable of pressing several bricks at a time and at a high speed. The hydraulic presses, though slower, yield a more consistent and often more heavily pressed product. The principal difficulty with the toggle type is that the stroke at any

time is fixed and the pressure applied to the brick varies with the weight of material in the mould and its natural packing density. Both with mechanical and hydraulic presses the special products are normally made with weighed quantities of batch and in the hydraulic press a moulding pressure of 15,000 lb./sq. in. is not unusual. Where the expense justifies it, large shapes, say 20 in. in length, can be made by fitting a special table to press one shape instead of the normal three standard squares. The use of such presses has led to a marked decrease both in porosity and permeability of refractories and a big improvement in perfection of shape and mechanical strength. They have been invaluable for producing the special shapes required for such jobs as suspended roofs, and hot metal mixer linings, the users being of the opinion that the extra cost involved is more than offset by the improved results obtained in service.

Drying

The floor and rack drying of bricks which was once standard practice is rapidly giving place to tunnel driers, which are closely controlled both as regards temperature and humidity. The use of such driers with fireclay enables the bricks to be dried more quickly and yet with reduced cracking, whilst with magnesite the ability to dry rapidly at a maximum temperature of, say, 60° C., has led to a great reduction in drying and kiln losses. It was at the beginning of the period under consideration that research showed that much of the cracking of magnesite shapes observed after firing was in fact the result of improper drying. Magnesia, like lime, tends to hydrate in contact with water, but the reaction rate at room temperatures is so much smaller that it had virtually passed unnoticed. At higher temperatures, say 90° C., and with fine grinding and high moisture contents, the rate of growth can be phenomenal, and even with dead-burned magnesite cracking and shelling can occur. Many floor-dried magnesite bricks showed no obvious cracks, but were in a state of strain after drying, as shown by their peculiar fracture when dropped.

The hydration of magnesia can also be a problem to the steelmaker, since under certain conditions, e.g., where wet bricks are installed in a hearth and heated up slowly, or where water from a cooler drips on a magnesite bank, serious hydration can occur and lead to complete disruption of the structure.

Firing

Perhaps the most remarkable development in the field of firing has been its complete elimination for certain products, particularly in the United States, where at least half of the present basic bricks are sold in the unfired state. This is not a new idea, since metal-cased bricks produced by ramming dead-burned magnesite into steel tubes were used even before the present period, but the use of unfired standard squares, either with or without steel sheets, is comparatively new and widely adopted. The benefits to the manufacturer are obvious, since the tiresome business of firing is completely obviated. The benefits to the user are by no means as clear, particularly since the price differential is small and often completely offset by the necessity of purchasing steel plates. The one clear gain is that rush orders can frequently be met within a week, where a month would be required for fired bricks.

Large quantities of unfired bricks, having a clipped-on steel case, or more recently an integral steel case, have been produced. With the latter a 'U' shaped steel liner is inserted in the pressbox, the refractory fed into it and the top side plated by a second steel sheet attached magnetically to the press-plunger. Both the 'U' shaped former and the top plate are fitted with lugs so that when the brick comes out of the mould it has firmly attached steel on four sides and is extremely true to shape. Such bricks can be handled without risk of breakage, and being extraordinarily accurate, are easy to build. They tend, however, to be expensive, and must lead to increased heat losses from the furnace due to the large amount of metal present. The question as to whether the use of unfired bricks, whether metal-plated or not, is economic, must be decided in relation to particular positions in particular furnaces. Some users claim that they are beyond doubt more economical than the fired product, while others maintain that for their purpose quite the opposite is true.

The other main development has been the extended use of tunnel kilns for the firing of fireclay, silica and basic bricks. These combine excellent high-temperature control even up to 1,650° C. with relatively short firing schedules. Where, as with chrome-magnesite bricks, a high-firing temperature is considered desirable, the use of a tunnel kiln offers considerable advantages.

The Product in Service

In conclusion we shall consider briefly the improvements that have resulted from the above changes in manufacturing methods :—

Silica.—The most important development here has been the attempt to produce, particularly in the United States, a super-duty silica brick, which has been defined as one having a total content of alumina, alkali and titania of less than ½%. Users of Findlings quartzite and more recently of South African materials are by no means certain that the titania should be included in the deleterious fluxes, since these particular rocks are high in titania (generally 1–2%) and yet give excellent service in open-hearth furnace roofs. What is certain is that a reduction in alumina content combined with decreased porosity can lead to a surprising increase in durability. Whether such improvement will be generally experienced will depend largely on whether advantage is taken of the increased refractoriness to increase production from the furnace. At one time an increase in the maximum safe temperature of 10° C. would not have seemed worth striving for, but we now know that due to the effects of the 4th power law of radiation and the small temperature difference between roof and bath, such an increase can have a very big effect on heat transfer.

Dolomite.—There have been big changes in the uses of dolomite during the last two decades. Not only have much improved hearths been developed by the use of novel gradings, e.g., the rice and flour mixture that originated from certain Italian work, and the much coarser controlled pan-milling technique developed in Great Britain during the war, but there have also been produced two new types of brick : the fully stabilised brick, consisting essentially of tricalcium silicate and magnesia, and a semi-stable brick—similar in composition to fettling dolomite but preformed and fired at a high temperature. The former are now accepted by many firms in Great Britain as the standard sub-hearth material for the basic open-hearth and arc furnace practice, while the latter have given and are giving

excellent service in the side-walls of basic arc furnaces and converters. Ordinary tarred dolomite can be used for this latter purpose, but the difficulty of ramming such a material adequately under plant conditions and the impossibility of firing it throughout by heating from one side make the fired brick a much better proposition.

Magnesite.—Sea-water magnesia is now employed for all refractory purposes. There were of course teething troubles in the changeover, particularly as the early batches of the sea-water tended to be high in lime (5–6%). With the present material, whose lime content is approximately $2\frac{1}{2}$%, excellent results are obtained even in such searching positions as the linings of induction furnaces and the roofs of all-basic furnaces. The results of years of service suggest that in these positions it is at least as good as the rival materials. The changeover revealed a unique and hitherto not understood problem with the induction furnace. Most induction furnace steelmakers had made use of basic linings from one firm that had proved satisfactory—at least in furnaces up to 2-tons capacity. When the Austrian and Greek magnesite, previously used, were no longer available, a spate of failures occurred due to the metal breaking through the lining to the coil. After a hectic period, in which such failures were numerous, a clue was obtained from a chance remark that the linings which cracked most seemed to be the safest. This indicated that the original objective of minimum shrinkage at high temperatures was possibly wrong and that volume stability at intermediate temperatures might be more important. Tests made on pre-war type linings—which contained among other bonds an appreciable amount of sand and borax—showed them to have an after-expansion of the order of 1–2% when fired at 1,150° C. This appeared to be due to the formation of a low melting point glass, which attacked the magnesia grains, coating them with a layer of forsterite. Once this was realised batches were prepared from sea-water magnesia, using similar bonds adjusted in quantity to give an expansion at 1,150° C. (one hour) of at least $1\frac{1}{2}$%. This proved to be a complete solution of the problem, resulting apparently in an intermediate zone which expanded and was, therefore, steeltight, even though the zone between it and the bath contained large cracks through which metal could readily penetrate.

Chrome and Chrome-Magnesite. The original straight chrome bricks used as a neutral course between magnesite and silica have been largely replaced by chrome-magnesite bricks, whose use has now spread in the all-basic furnace to virtually the whole of the open-hearth structure above sill level. The economics of such furnaces is still in the balance, but recent results both in this country and on the Continent suggest that the turning point has been reached and that wider application may now be expected. There is little doubt that of all the procedures so far suggested for increasing output from open-hearth furnaces, e.g., oil firing, modifications in design, and the use of oxygen, the all-basic furnace stands out as the potential leader. Given adequate charging facilities an increase in production of 30 or 40% should be quite possible with a rise in roof temperature from the 1,650° C., normally adopted for silica, to, say, 1,700° C. for a basic roof.

The roof problem has been tackled in numerous ways, the two most encouraging at the moment being the Continental type, in which the roof consists of a series of ribs attached to steel 'T' irons by means of wires, together with intermediate courses of 3, 4, or 5 bricks, and the non-ribbed American type roof, in which each pair of bricks is suspended on an independent steel hanger. The advantage of the latter procedure is that it reduces the compression load between the courses, but this may ultimately prove to be a limited gain, since it can result in a large sideways movement and associated distortion of the roof structure.

Alumino-Silicates.—The improvements obtained with fireclay bricks have not been so sensational, but there is no doubt that the open-hearth checker-brick, the ladle brick, and the blast furnace lining of to-day are markedly better than their forbears of twenty years ago. There has been a tendency to go for smaller blocks of accurate dimensions and perfection of shape, often made by dry-pressing and subsequent firing at high temperatures. Although this field is one in which experience is longest it is also probably that in which our ignorance is greatest. Reactions of fireclay with, say, basic slags, necessitate the study of complex oxide systems at high temperatures and any attempt to simplify the problem by neglecting certain of these may well lead to a wrong answer. What is certain is that any metallurgist desiring to test bricks of a wider range of alumina content can now do so.

Forsterite.—The necessity for finding substitutes for chrome ore during the last world war led to intensive research on serpentine, both as a material for making forsterite ($2MgO.SiO_2$) type bricks and as a parging material for use in open-hearth furnaces, where chrome-magnesite cements had previously been used. Batches of the 80% serpentine—20% magnesite type appeared to be quite satisfactory, the amount of magnesia present being in excess of that needed to convert the serpentine to forsterite. It is possible that fired bricks of this composition, which have already found uses, for example in arc furnace side-walls, will ultimately find other applications, e.g., as checker-bricks. They have already proved their value for this purpose in the glass industry, where they show a far better resistance to alkali fluxes than the normal fireclay product.

Carbon.—Nothing has been said under manufacturing methods concerning carbon bricks, but considerable improvements have been made in processing, and these have led to the production in this country of carbon blocks having far better mechanical properties than those previously available. The result of several years of joint development between the carbon manufacturers and the blast furnace operators has been the production of several furnaces lined from top to bottom with carbon. Earlier work on the Continent had already shown that the use of well designed carbon hearths and bosh could result in considerable reduction in operating difficulties, and in particular provide the most hopeful solution to the breakout problem. The latest results, although still very much in the experimental stage, suggest that the use of carbon in the stack may help to solve the blast-furnaceman's next greatest worry, viz.: scaffold formation. The basis for this hope lies in the fact that there is virtually no adhesion between burden material and carbon bricks, whereas burden sticks at relatively low temperatures to all the other refractories so far tested.

Both the refractories manufacturer and the furnace builder can be proud of the achievements of the last twenty-one years. They cannot, however, afford to rest on their laurels, for it is still true that refractories are a limiting factor in furnace design and operation.

Changes in the Non-Ferrous Metals Industry

By William H. Henman
President, British Non-Ferrous Metals Federation.

Many changes and improvements have been effected in the non-ferrous metals industry during the past 21 years, but Mr. Henman, who this year has completed 50 years' active work in it, has prepared a wider picture from the beginning of his industrial career during which remarkable changes have been effected. He compares early conditions with those of to-day and refers to enormous advances on the material side. Particular mention is made of the spirit of co-operation, understanding and mutual help which characterises the relations of firms in the industry to-day. The dominant impression of a life-time's work is one of continued and ever more rapid progress.

An oil-fired melting unit at the works of The Phosphor Bronze Co., Ltd.

LET us imagine a non-ferrous metal fabricator of 1900 returning to his factory to-day after a 50 years' absence. The old place is almost unrecognisable. The whole scale of his plant is probably enormously greater: it covers more floor-space and has quite probably pushed upwards towards the skies as well. Quite apart from physical size, everything else has changed also. The virgin metal which arrives at his raw material store is itself of a higher degree of purity than would have been thought possible in 1900. (It would perhaps be prudent at first not to emphasise the fact that the price of raw material has multiplied by about 10 times since 1900). Passing from the metal store to the casting shop, gone are the old coke-fired furnaces and clay crucibles in which with great caution and many mishaps his contemporaries struggled through five heats a day, renewing the crucible daily. In the mill itself, gone is the solitary steam-engine which laboriously motivated long clanking trains of open cast-iron gearing to drive the rolls and drawbenches. No longer does the whole works periodically close down for 10 minutes at a time while a minor breakdown in one part of the mill is isolated by stopping the engine and throwing a clutch or removing a spindle. Gone, too, are the slowly-revolving cast-iron rolls, constantly scoured with emery powder and scouring stick: gone are the drawing-dies which have to be so frequently "knocked-up" to the correct size from which they have opened in working. The labour force has changed, too; there seem to be fewer heavy manual workers, and a completely new type of individual has also found his way on to the shop floor—white-coated, scientific and indispensable. In the place of all that he knew there is a clean, modern, spacious mill, driven by electric power, working throughout under close scientific supervision and producing in unimaginable quantities a product of uniform consistency and the highest quality and finish.

The developments in the non-ferrous metal fabricating industry in the last 50 years have, in fact, been fundamental and widespread. The changes have been so extensive that it is not easy to pick out the high lights. Other contributors are treating various metallurgical aspects, and within the limits of space available this article seeks to deal with the structure and standing of the industry as a whole and with some of the more important developments in major processes.

Since the turn of the century, the structure of the industry has very considerably changed. The tendency has been for the growth of larger and larger units, covering an ever-increasing range of products. This has been achieved partly by the amalgamation of a number of small production-units into larger organisations and partly by the natural growth and expansion of individual units and a tendency to increase the range of production. With one or two notable exceptions, the majority of firms in the industry to-day do not specialise in one product only, but combine a wide range into a balanced production programme. Within recent years

the pace of structural change appears to have slowed down and it has been extremely rare that manufacturers have gone out of production. The industry to-day presents a varied picture, including at one extreme a number of large all-purpose mills and at the other a number of small specialist houses. There is ample productive capacity available for all purposes from the long run of standard products down to the highly specialised "tailor-made" trade.

Parallel with the development in structure has been a marked improvement in what may be called the standing of the industry and in the creation of collective organisations. The first important step was taken as long ago as 1908 when the Institute of Metals was first formed. There is no doubt that this body has had a very considerable influence on the development of metallurgical education and training since that date, and thus both directly and indirectly on the growth of scientific metallurgical control of production. The formation by the producers, manufacturers and users of non-ferrous metals of the British Non-Ferrous Metals Research Association in 1920 marked a further step forward, which was to be consolidated some years later when the work of the Association was concentrated in London and fully equipped and completely modern laboratories and ancillary premises were opened. In 1933, the Copper Development Association was formed with a view to promoting the use of copper and copper-based alloys by collecting and disseminating information, chiefly technical. The Zinc Development Association was founded in 1938 for similar purposes. Mention must also be made of the British Non-Ferrous Metals Federation formed in 1945 as the representative organisation of the fabricating industry, which in the comparatively short space of 5 years has been nationally and internationally recognised as the authentic and responsible voice of the industry. Finally, the dependence of modern leaders of industry upon reliable and prompt economic and statistical information gave rise to the formation by the producers, refiners and fabricators of the British Bureau of Non-Ferrous Metal Statistics. It will thus be seen that in all important aspects the fabricating industry has, in the last 50 years, become suitably organised and has acquired, as it were, a collective personality and a high sense of responsibility. The effects of this movement have made themselves felt in many ways, but since the scope of this article is technical rather than economic, emphasis must be given to the truly remarkable development of training and education in scientific metallurgy, and the consequent improvement in production technique and in manufacturing standards. It would be improper to pass from this subject without paying a tribute to the invaluable work over many years of the University of Birmingham and its Department of Metallurgy. The high value placed upon this institution by manufacturing industry was strikingly demonstrated a few years ago when the industry contributed very largely to the endowment of a Chair of Industrial Metallurgy in that Department. The wisdom and practical value of this step have already been well demonstrated by the high quality of scientific graduate now being made available to industry.

In many ways it is the new role of the scientific metallurgist in manufacturing industry which is the most outstanding sign of change since 1900. It is true, and it should never be forgotten, that the skilled working craftsman of the old days, without scientific aid produced a high quality product and had a traditional knowledge of many of the scientific principles of to-day though he might perhaps have formulated them in the language of the mill rather than that of the laboratory. But his knowledge was the craftsman's knowledge, compounded of shrewd observation, common sense and learning handed down from generation to generation. For many years after 1900 the metallurgical chemist was only a rare bird in the works, and where they were employed, they were chiefly concerned with elementary chemical analysis only. To-day the microscope, the pyrometer, the spectograph and a mass of modern equipment are the commonplace of the works metallurgist and scientific control is exercised at every stage of manufacture.

One principal result of extended research has been the absolute purity of alloy now obtainable. Credit for this must go largely to the producers and refiners who are now able to produce by electrolytic processes virgin metals with the minimum of impurities. The availability of such material and the advent of the electric furnace have now enabled the fabricator to exercise the strictest control over his melt and to produce material of almost any desired chemical and mechanical properties.

Another marked improvement resulting from scientific research and improved machinery is to be found in the quality and finish of British products. Fifty years ago it was, unfortunately, true to say that the British Industry as a whole was a long way behind the German Industry in this particular respect; to-day, however, it is happily true that we are second to none for the quality and finish of our products. The industry is at present awaiting with eager anticipation the report of the Productivity Team which has recently returned from a visit to the United States of America under the auspices of the Anglo-American Joint Council on Productivity. We have every confidence that while the American Industry may have certain advantages in manipulation arising from the longer runs which are open to them, we need fear no comparison with them on the grounds of quality and finish.

The two major wars of the last fifty years, 1914–1918 and 1939–1945 contributed very largely to the revolutions which have taken place in the fabricating industry. In both cases there was a sudden and unexpected demand for the production of enormous quantities of material of uniform standards. The industry on both occasions devoted itself whole-heartedly to solve the problems involved, and the lessons learned in war-time have been carried over into the epoch of peace. Uniformity of properties, composition and standards over very long runs can now be achieved for any purpose without presenting any serious problem.

In the space which remains it is time to take a look in greater detail at some of the major changes in the principal processes of the industry.

Casting

In this field the fundamental change has been the supersession of crucible casting in coke fire furnaces by the electric furnace which is now almost universally used. The major result of this has been a greater uniformity of melt and more accurate temperature control. The number of skilled workers which it is necessary to employ on this process has been reduced, while the possibility of

casting larger and heavier ingots has also enabled time and labour to be saved on handling and subsequent processing. An additional factor which has added importance in the present circumstances of scarcity, is the substantial saving in metallic loss under the new methods. The economic aspects of these methods are being increasingly appreciated.

Since this article deals with the last fifty years it is perhaps hardly yet appropriate to speak at any length of the comparatively new development of continuous casting. This method has not yet been commercially exploited in this country on any large scale, but there are many industrialists and technical experts who believe that the general adoption of continuous casting will prove to be one of the major developments in the fabricating industry in the immediate future.

The great strides which have been made by the industry are largely due to the vastly improved power plants and transmission available to the manufacturer to-day. The general use of electric power and the ease with which such power is transmitted have revolutionised the design of fabricating machinery and the lay-out of plant. It is now much more easy to isolate plant and to economise space. Great flexibility in performance and speed is now possible. Progress in machine design, the use of water-cooled or roller bearings and improved methods of lubrication have made it possible to achieve extremely high speeds of rolling and drawing. The roll-makers have themselves improved their own product, and the use of alloy steels has permitted the production of rolls of 100° Shore hardness compared with 65–70° for the old cast-iron or "semi-steel" rolls. Improved polishing methods have encouraged superior surface finish of metal. New and improved designs of rolling-mills have been generally installed and have resulted in much greater reductions of metal combined with more uniform rolling. A revolution has taken place in wire drawing as a result of the introduction of tungsten carbide dies and multiple hole drawing. The principle of multiple operation is also contributing to increased productivity in the tube industry, through the use of multiple reducing machines.

Annealing, like other processes, has undergone a revolutionary change. In the early part of the period under review, annealing was normally carried out in coke or coal-fired open furnaces, and the material was exposed to smoke and other products of combustion, with undesirable results. Under the most modern system annealing is done electrically in a controlled atmosphere and oxidation is largely eliminated. Methods of pickling and cleaning have also similarly improved. There is no space to give more than a passing mention to the great progress which has been made in such things as flattening and shearing machines, straightening, etc., and in the very important field of protective coating.

Looking back over the last fifty years those who have, whether as industrialists or scientists, played a part in the truly remarkable development of the industry have every cause for pride. There have been some losses; the almost complete disappearance of the small family business and the growing scale of operations have made it more and more difficult to keep the close personal touch, both with employees and customers, which was characteristic of the industry before 1900, and indeed much later. In common with the greater part of British industry, the fabricating trade now draws much of its leadership and inspiration from management rather than from ownership. Much has been said in this article in praise of modern developments in machinery: it cannot, unfortunately, be said that modern machines are cheaper than their nineteenth-century counterparts, not through any fault of the machinery-makers. The capital outlay which is now necessary to equip an efficient modern mill is beyond the reach of many small or medium concerns. As these words are written the price of materials like copper, lead, zinc, nickel and tin, already high all over the world, show no signs of falling. Thus, to the large capital cost of plant and equipment must be added the heavy burden of financing basic and working stocks of raw materials. It would, therefore, appear that the recent tendency towards larger production units, with correspondingly larger financial resources, must continue. This is no doubt the march of progress and cannot be arrested even if we would. One who has completed fifty years of active work in the fabricating industry may perhaps be forgiven if he confesses to an occasional feeling of nostalgia. The dominant impression of a life time's work, however, is one of continued and ever more rapid progress in every department of the industry, and not least in conditions of labour. May those who write the corresponding article for the period ahead be able to say as much.

Copper During Metallurgia's Lifetime

By E. Voce, M.Sc., Ph.D., F.I.M.

Copper Development Association

The extent of present knowledge of copper is of a very high order and astonishing though it may seem, a large part of it has been gained during the last two decades. Especially is this true of improved alloys and of enhanced efficiency in methods of fabrication. The period under review has also witnessed a great expansion in the use of copper.

LOOKING back over the two short decades during which METALLURGIA has watched the progress of the copper industry, one is astonished, not so much that the extent of present knowledge is so great, but rather that so large a part of it has been gained in so brief a period of time. Much of the lore that now forms the basis of the copper metallurgist's craft was undreamed of, or only dimly perceived, a quarter of a century ago. Especially is this true of the development of new and improved alloys and of enhanced efficiency in methods of fabrication, for changes in the technique of extracting copper from its ores, though important, have been less revolutionary.

A glance at the A.I.M.M.E. "Rocky Mountain Fund Volume on Copper Metallurgy," published in 1933, shows that in the early years of the period under review the

direct reverberatory smelting of wet concentrate to matte was already widely practised, while electrolytic refining had long been well established. On the other hand, the electric remelting of cathode without the usual fire refining cycle, to produce tough pitch copper or the oxygen-free high conductivity type had not then been developed. Moreover, interest in the now moribund blast furnace method of producing matte was then much more real than it is at present, a change attributable to the increasing use of flotation concentrate, which is unsuitable for turbulent blast furnace treatment and demands the more quiescent reverberatory. Strange as it may seem, progress has come full cycle, for in the development of flash smelting, as already practised in Finland and shortly to be operated in Canada, turbulence is an essential feature of the process, the preheated concentrate being blown by hot air into the furnace where it ignites, melts and coalesces to form matte.

Though world production of copper had reached a peak of some 1,700,000 tons coincident with the birth of METALLURGIA in 1929, it fell to little more than half that amount during the slump of the early '30's. Paradoxically this period witnessed commencement of production on the Northern Rhodesian Copper Belt, from which we now draw so much of our supplies. Largely to meet the demands of war, production rose to the record height of about 2,700,000 tons in the middle 1940's, and though there was a substantial diminution as hostilities drew to a close, there has since been an increase, probably attributable in some measure at least to recent stockpiling policy.

Looking at the home picture, it is noteworthy that both our two large fire refineries at Prescot and Enfield respectively, are junior to METALLURGIA. It remains problematical whether Britain will ever see the establishment of an electrolytic refinery of magnitude comparable with these. While the low-frequency electric melting and hot rolling of brass has greatly increased and is now almost universal practice in this country, we have as yet no unit comparable with the enormous modern American plants based on continuous casting followed by fully mechanised rolling mills.

Melting and casting problems have been made a special study by British metallurgists, special attention having been paid to the effect of gases dissolved in the molten metal. The classic researches of Allen on the equilibrium between hydrogen and oxygen in molten copper laid the foundation for the independent investigations of Baker and Pell-Walpole and their colleagues on the casting of bronzes and gunmetals, and, perhaps less directly, for those of Genders, Bailey and others on the casting of brasses. It is a fitting tribute to these labours that recognition has been given by the British Standards Institution in their recently published " Code of Practice for the Inspection and Testing of Copper Alloy Sand Castings " to the principle that it is the main function of a test bar to indicate the quality of the melt, especially in respect of gas content, rather than to reveal the properties of the casting it represents. Although so much of this work has been British, recognition must also be given to the American workers from Ellis to Eastwood and Kura, as well as to Lepp, of France, whose original patents on the degassing of tin bronze were revolutionary in their day, and whose more recent work on the application of thermodynamical principles to slag reactions in general and to copper smelting in particular have proved highly stimulating.

Apart from the old established brasses, bronzes, gunmetals, cupro-nickels and nickel silvers, it is true to say that almost the whole of the extensive array of copper-base alloys which now meet the varied needs of industry have been developed within the couple of decades. In the late 1920's and early 1930's the aluminium bronzes were still struggling for recognition in the hierarchy; now they are accepted among the strongest and toughest of the copper-base alloys, with excellent resistance to creep and fatigue as well as to oxidation and scaling at elevated temperatures. For such reasons they are becoming increasingly important in connection with gas turbine development, both for compressor blades and heat exchanger tubes. Only a few years ago aluminium bronze was regarded as almost impossible to weld, but modern effort has developed arc welding techniques which not only give perfectly satisfactory joints but which are as easy and reliable to carry out as those for the welding of steel. This fact, coupled with their high resistance to cavitation erosion in sea water has contributed to the increasing popularity of the aluminium bronzes for ships' propellers, particularly those of the smaller high-duty type. Large propellers (and some of the largest ever made have been cast within the period under consideration), are still mainly produced from high tensile brass or "manganese bronze" as it is so frequently inappropriately called.

In the early days of METALLURGIA the silicon bronzes and brasses were attracting considerable attention, the former mainly on account of their resistance to acidic corrosion and the latter as strong, relatively cheap materials for general engineering purposes. Both have continued to make progress during the intervening years, especially when, through the exigencies of war, shortage of tin made substitutes for the true bronzes indispensable. Silicon bronze is one of the easiest of the copper-base alloys to weld, and this, together with its good general resistance to corrosion, has established it as an additional material of value for chemical engineering plant, and its use is not by any means limited to this field.

Consideration of corrosion brings thoughts of aluminium brass and iron-bearing cupro-nickels, both of which have been developed by patient research to meet the exacting conditions imposed on the tubes of marine condensers. Formerly the principal material for this type of service was Admiralty brass, i.e., 70 : 30 brass containing 1% of tin. Experiment showed, however, that replacement of the tin by 2% of aluminium greatly improved the resistance to impingement attack by moving sea water, because an invisible, self-healing, protective film of aluminium oxide formed spontaneously on the surface of the alloy. The addition of a very small amount of arsenic helps to protect the brass from dezincification. Copper containing 30% of nickel has long been recognised as an excellent, though somewhat expensive material for marine condenser tubes, but modern research has shown that the nickel content can profitably be reduced to less than one-third of that amount, without detriment to the resistance to impingement attack, if a small quantity of iron is added to the alloy. These developments did much to cure a major headache of the Admiralty during the war by ensuring that H.M. ships rarely went to dock for treatment of " condenseritis."

A little before METALLURGIA came into being, pioneers like Corson had been examining the precipitation hardening of copper-base alloys, and soon afterwards a

wide range of materials of this class were developed. A considerable proportion of them received scant commercial attention but at least six types have become established industrially. Of these no less than four contain nickel in conjunction respectively with silicon, aluminium, tin and phosphorus, while the remaining two are chromium copper and, paramount among them all, beryllium copper.

When silicon co-exists with nickel, whether the matrix be substantially pure copper or cupro-nickel, precipitation hardening effects occur due to the decrease with falling temperature of the solid solubility of nickel silicide. One of the best known commercial alloys of this type contains nickel and silicon in just the correct proportion to form the compound, so that the matrix in the precipitation hardened condition remains relatively free from elements in solid solution and therefore has good thermal and electrical conductivity. An important use of such material is for locomotive firebox plates and stay rods. Comparable in properties are the alloys which rely on the precipitation of nickel phosphide, but they have not attained great prominence in this country. Here, however, considerable interest is taken in the alloys dependent for their precipitation hardening properties on the presence of a stable intermetallic compound of nickel and aluminium. The matrix may be either copper or brass and, particularly in the latter form, the alloys are suitable for the production of diaphragms, light springs and similar mechanisms. With certain combinations of tin and nickel, precipitation hardening properties are exhibited by the nickel bronzes. Such alloys are used mainly in the form of castings for general engineering purposes, where greater strength and hardness than those obtainable with ordinary bronzes and gunmetals are desired.

In the precipitation hardened condition, copper containing about 0·5% of chromium has excellent conductivity combined with good strength and toughness. It is widely used both in the cast and wrought forms for many electrical and general engineering purposes, such for instance as welding electrodes and electrode holders and the cylinder heads of high-duty internal combustion engines. Wrought chromium bronze, containing tin as well as chromium, has been found to be satisfactory for the manufacture of light bearings, generally of tubular form.

A great deal more use would undoubtedly be made of beryllium copper if the price could be brought down and in this respect it is unfortunate that beryllium has to be imported against the adverse dollar exchange. Nevertheless beryllium copper is a valuable industrial alloy on account of its outstanding hardness and strength in fatigue as well as tension. It also possesses greater conductivity than any other material of comparable mechanical properties. An important application is for cutting and other tools for use under conditions where there would be risk of explosion due to sparks if steel were employed, but the main attraction of beryllium copper is for instrument springs, bellows, pneumatic capsules and similar purposes. These can be formed while the material remains in the soft condition and afterwards hardened by a simple heat treatment at a temperature but little above 300° C. The method is so convenient and reliable in comparison with that required to form work-hardened materials into springs, that the higher cost of beryllium copper is often more than offset by the relative freedom from rejects. The modulus of elasticity is less than two-thirds of that of spring steel, so that much greater deflections are obtainable for similar loads, with consequent improvement in the sensitivity of response. Advantage may be taken of this fact in designing the control springs of instruments. Moreover, for electrical applications, beryllium copper has the advantages over steel of improved conductivity and freedom from magnetic properties. In addition it is much more resistant to corrosion.

For a considerable number of years, though well within the period under review, researches have been proceeding in America on the production of pure manganese and on the properties of its alloys. The well-known high specific resistance and low temperature coefficient of certain of the binary copper-manganese alloys has been confirmed, and it has also been shown that under certain conditions they evince abnormally high damping capacity. White brasses containing manganese may be attractive in appearance but they seem to have little advantage over ordinary brasses and nickel silvers in mechanical properties. One series of manganese alloys does, however, call for special mention, namely that based on copper with up to 20% each of nickel and manganese in approximately equal amounts. By suitable heat treatment, mechanical properties comparable with those of beryllium copper can be imparted to these materials, but the interesting thing is that this is attributed, not to precipitation, but to "ordering" of the crystal lattice. In no other alloy system has "ordering" yet been found to have so pronounced an effect.

Two important electrical alloys, silver-copper and cadmium-copper, are now firmly established, and it is difficult to credit that the former, unlike METALLURGIA, has not yet attained its majority; cadmium–copper, although first used in the 1920's, has made great commercial strides during the past twenty years. As is well-known silver-bearing copper is exploited for its improved resistance to annealing during soft soldering or stoving operations, but recent research has clearly demonstrated that its creep properties are markedly better than those of ordinary high conductivity copper. Cadmium–copper is firmly established in this country for transmission lines of long span, trolley wires and welding electrodes, but is less widely used in other parts of the world. A comparatively new member of this electrical group is tellurium copper, which combines free machinability with high conductivity, while the recently developed conductivity wires consisting of copper with 6–7% silver and 10–15% iron respectively, should also be mentioned. By suitable combinations of cold work and heat treatment, strengths up to 70 tons/sq. in. or more are claimed with conductivities upwards of 55% I.A.C.S.

The outstanding progress of powder metallurgy cannot be overlooked in this review. Chief among the uses of copper powder is the production of porous bronze bearings and filters, but it can also be combined with other substances, such for instance as graphite in the manufacture of brushes for electrical machines. Powder metallurgy is one of the established methods of making the now well-known copper-lead bearings which have proved so successful in internal combustion engines and similar applications. Alternatively these bearings are produced by casting, generally by semi-continuous methods, on to steel shells, which are afterwards formed to the required size and shape in power presses.

As a background to the numerous practical developments already described, a great deal of research of a more fundamental character has been taking place during the period under review. Without belittling other organisations and individuals there can be no doubt that, as far as copper is concerned in this country, the two mainsprings of this type of information have been the B.N.F.M.R.A. and the Research Laboratories of I.C.I. From its inception the B.N.F.M.R.A. has been deeply concerned with the effect of addition elements, whether intentional or as impurities, on the properties of copper, much attention having been paid to the highly detrimental element, bismuth. The interests of the Association have, however, ranged much more widely than this, from casting to spectrographic analysis, from corrosion to creep. From I.C.I. in recent years have come important fundamental researches on the preferred orientation and annealing characteristics of copper and brass, and on the mechanics of cold rolling and " homogeneous " deformation. Our American friends have not been behind in such matters, and special mention should be made of some exceptionally careful work on the electrical conductivity of super-pure copper containing small controlled amounts of various other elements.

Though many a copper roof has stood the test of time for more decades than METALLURGIA can boast years, it is nevertheless true that the Journal has witnessed an almost phenomenal expansion in the use of copper for this and similar purposes. Not only has many a notable modern building, such for instance as Liverpool Cathedral, been roofed with copper, but literally thousands of humble " pre-fabs " have been dignified in the same way. In plumbing, too, copper has achieved marked success and there can be no doubt that, in connection with the building trade generally, copper has now definitely " arrived."

Nickel and Nickel Alloys

A Review of Progress Since 1929

By L. B. Pfeil, O.B.E., D.Sc.

Nickel plays so important and varied a part in industry generally that a complete survey of the progress achieved in the development of its applications during the period is not possible in the limited space available. For this reason, some developments—notably nickel steels—have been omitted, but the author presents adequate evidence of its great progress in many fields.

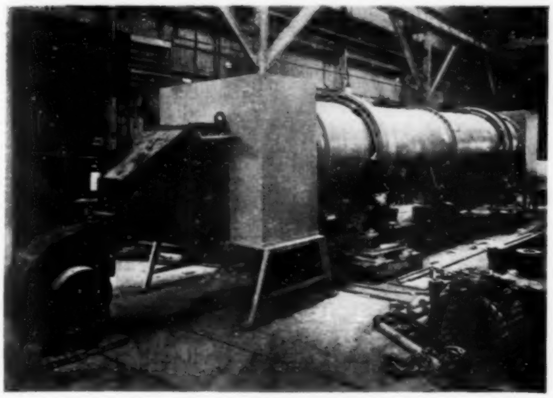
DEVELOPMENTS in the field of wrought non-ferrous alloys containing nickel have, during the past twenty-one years, been concerned with a general improvement of the range of properties made available through them. Thus, there have been improvements in workability, mechanical strength and corrosion- and oxidation-resistance. Even that most ancient of alloys, nickel silver, has been affected by the changes made, and many new alloy compositions have been introduced during this period.

The problem of increasing workability has been approached primarily by careful control of melting and casting procedure, which has not only enabled former difficulties, due to hot shortness and similar phenomena, to be overcome, but has also made possible maintenance of close control of physical properties of the alloys. Thus, grades of nickel are now available with very high temperature coefficients of resistance, for use in resistance thermometers, and yet other grades provide the properties required for the manufacture of electronic valve coated cathodes for giving a definite rate of activation of the coating. Without this development of techniques for accurate control of composition and improved workability of nickel alloys many of the new developments mentioned below would have been impossible.

Edge of turbine rotor for jet engine showing Nimonic alloy blades.

Exploration of the effects of additions made during the melting of alloys has led to the development of machinable grades of well-established materials. The addition of sulphur to the nickel-copper alloy, Monel, and of carbon to nickel, has resulted in the production of machinable grades of these alloys, without loss of mechanical strength or corrosion resistance. Again, by slight modifications of their composition, precipitation-hardening forms of nickel-base alloys providing considerable improvement in the mechanical properties have resulted. Instances of this are K-Monel and Duranickel, two alloys developed during the period under review, both of which, after suitable heat-treatment, show tensile strengths of over 90 tons/sq. in., whilst retaining the corrosion-resisting properties of the parent material.

Modern industrial plant requires materials to resist conditions of service of ever increasing severity, both as regards strength and oxidation-resistance at high



Salt drier with solid Monel shell and Monel flights.

temperature, and corrosion-resistance. Undoubtedly of outstanding interest are the improvements which have taken place in high-temperature resistance alloys. Not only are there now available electrical-resistance materials usable at temperatures as high as 1250° C., but the development of the Nimonic series of alloys makes available wrought material with considerable creep resistance under stress, even at temperatures as high as 870° C.

Both types of alloy are derived from the 80% nickel, 20% chromium base. In the case of electrical-resistance materials, the alloys have been modified by small additions which have been shown to result in the formation, on oxidation, of a highly protective scale; in the Nimonic series of alloys the basic composition has been modified by additions of titanium and aluminium in carefully controlled ratio, which additions make the alloy capable of being precipitation-hardened. In certain instances, in the Nimonic series of alloys, the basic composition has been further modified by additions of cobalt or iron.

Suitably heat treated (by a solution treatment at about 1080° C. and a precipitation treatment at about 700° C), members of the Nimonic series offer a range of high-temperature creep-resistant properties which has resulted in their universal adoption for the moving turbine blades in all British aircraft gas turbines in production today. As an example of the properties obtainable through these alloys, the latest addition to the series—Nimonic 90, in which the basic composition has been modified by the addition of a proportion of cobalt—is manufactured to meet the specification that at a temperature of 750° C. and under a tensile stress of 19 tons/sq. in. its rate of creep in secondary creep shall not exceed 0·01% per hour, it shall not enter the tertiary stage of creep for 50 hours, and shall not fracture before 75 hours have elapsed.

These Nimonic alloys have proved their value in a wide variety of applications not connected with gas turbines—such as high-temperature springs, woven wire, furnace belting, high-temperature valves and valve seats, and many other applications where strength at high temperatures is required. In the cold worked and heat-treated condition they show tensile strength in excess of 100 tons/sq. in., whilst retaining a reasonable degree of ductility.

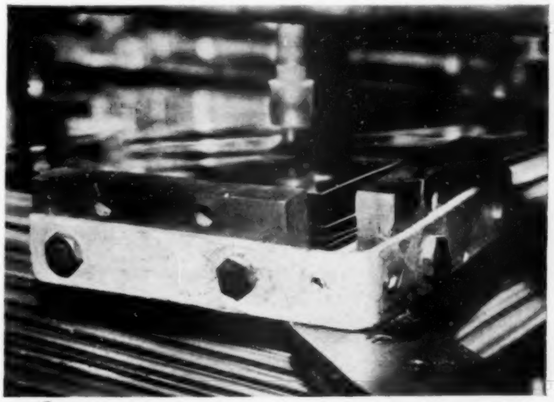
The increasing demand for corrosion-resisting materials, to meet the more severe conditions imposed by the chemical and other industries, has led not only to the modification of established alloys, but also the development of new materials. The old-established 70/30 copper-nickel alloy used for the tubing in steam condensers has proved insufficiently resistant to the more severe conditions of service of modern plant, but by the addition of small percentages of iron and manganese, this alloy has been rendered capable of meeting any service condition now imposed. Accompanying this development, completely new low-nickel cupro-nickel alloys containing small percentages of iron have been evolved, to replace copper, which has failed when subjected to the higher water speeds used in sea-water trunk lines in certain modern ships.

The commercial development of the Hastelloy series of nickel-molybdenum, nickel-molybdenum-chromium and nickel-silicon-base alloys has made available to industry materials of construction which will withstand the most severely corrosive conditions, such as occur when handling chlorides, sulphuric acid and similar very corrosive media.

The development of techniques for the manufacture of clad steels now provides industry, at a relatively low cost with the corrosion-resisting properties of nickel and high-nickel-content alloys which, if available only in the solid form, could not be used for economic reasons.

Nickel-Iron Alloys

An outstanding feature in technical progress in the last twenty-one years is the widespread adoption of special electrical and electronic equipment in industry,



Showing a new application of nickel-iron-aluminium alloy permanent magnets based on the principle that when a pile of steel sheets is placed in a magnetic field, the sheets being magnetised with like polarity repel one another, and the top one floats above the rest and may readily be picked off.

is communications, in the home, and in medical science. In this connection, radio, television, radar and therapeutic apparatus all come to mind. The rise of this new field of technology has depended on the use of new alloys possessing special physical and mechanical properties.

Many of the special-purpose alloys are based on the nickel-iron series. This series has, among others, two characteristics of major interest. First, alloys in this series show a complete range of thermal-expansion coefficients from almost zero up to eighteen millionths per degree Centigrade, and secondly, the series includes alloys covering a wide range of magnetic properties,

Showing a mould for the production of a razor case in plastic material. The negative portion of the razor case die is in electro-formed nickel.

from those which are completely non-magnetic to those showing the highest magnetic permeability. These ranges of properties may be enhanced, and other useful properties added, by the inclusion of further metals in the alloy system and by heat-treatment, thus leading to some of the special-purpose alloys mentioned below.

The low-expansion nickel-iron alloys (e.g. Invar, Nilo 36, etc.) are widely used in the construction of temperature-control apparatus now common in every home for the thermostatic control of gas and electric ovens, water heaters, central heating, electric irons, and so on. They also figure in safety devices which cut off the gas supply to water heaters should the pilot jet become extinguished. In all these cases, operation of the equipment depends on the relative movement of high- and low-expansion members. The low-expansion alloy is also used in the construction of instruments and equipment where constant dimensions must be maintained with varying temperature. Alloys with selected intermediate expansion rates have been developed to match different types of glass used for radio valves and kindred equipment. Such alloys are now widely used in glass-metal seals for valves of all types, and for the hermetic sealing of apparatus against tropical conditions.

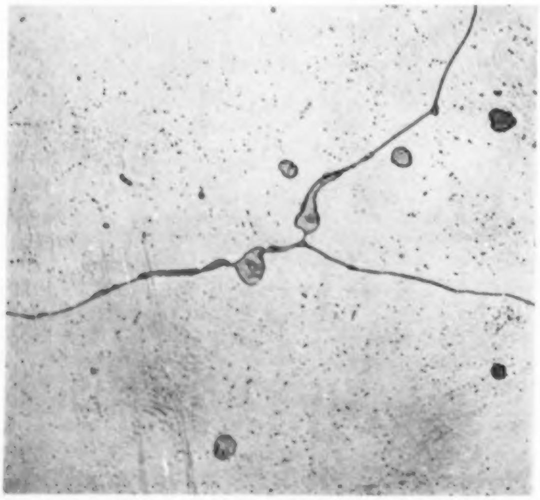
Some of the low-expansion alloys have been modified to combine other special properties, such as a constant elastic modulus with varying temperature, in conjunction with high-grade mechanical properties. These are important for precision springs for clocks and watches, and measuring instruments of all types. New uses include devices incorporating vibrating reeds for frequency control in electronic equipment.

The high magnetic permeability of certain nickel-iron alloys has been used for some time past in communications engineering. Further improvement in properties has been gained by modification of composition and structure, especially to meet the needs of television and radar. The alloys are also extensively used as magnetic shields in high-frequency equipment. Certain alloys of nickel with iron or copper are also used for the temperature compensation of instruments, on account of their rapid change in magnetic characteristics with temperature variation, as experienced, for example, in aircraft.

One of the most striking metallurgical developments of the past 21 years is that of the nickel-aluminium-iron alloys for permanent magnets. Further development in this series, by the addition of cobalt and of small amounts of other metals, and later by heat-treatment in a magnetic field, has made available magnets with five or more times the power of the best magnets commercially known in 1929. The new magnets are widely used in radio loudspeakers, television focusing, magnetic chucks, and numerous other devices.

Non-Ferrous Castings

Twenty-one years ago the development of nickel and nickel-alloy castings was in its infancy, and the materials in service could be broadly grouped under four headings :



Cast Monel containing 0.053% sulphur. No magnesium. Note the brittle nickel sulphide constituent around the grain boundaries. × 250

Cast Monel containing 0.089% sulphur and 0.10% magnesium. Note the effect of magnesium in preventing grain-boundary nickel sulphide. × 250

(Reduced to ⅞ linear on reproduction)

Cast nickel graphitic with the graphite in nodular form. × 100

Cast graphitic nickel with the graphite in flake form. × 100

(1) nickel castings; (2) nickel-copper-silicon alloys, such as Monel; (3) heat-resisting castings of the nickel-chromium-iron type, and (4) special high-nickel bronzes, with or without the addition of lead, as used for steam-valve seats, etc. Furthermore, very little reliable practical information was available on production technique and, as a result, the quality of castings was not always of a satisfactory commercial standard. Today, not only have new alloys been introduced to meet modern industrial needs, but a very marked improvement in casting quality has been effected. In the space available it is quite impossible to give a complete outline of all developments in this field; one or two typical, but interesting, examples must suffice to show the progress made during the past twenty-one years.

As a result of research and production experience, a great deal of new information has been obtained, for instance, on the effect of trace elements such as carbon, sulphur, lead, etc., on the properties and quality of nickel and nickel-alloy castings. Sulphur is decidedly objectionable, as little as 0·05% making cast nickel and Monel excessively brittle at both room and elevated temperatures. The effect of this element is due to the formation of intergranular films of nickel sulphide, which melt at about 630° C. and are very brittle at normal temperatures. Magnesium has, however, the property of neutralising this effect, by forming high-melting-point magnesium sulphides, distributed throughout the metal in small particles which do not reduce mechanical properties as do grain-boundary nickel sulphides. The results shown in Table 1, and the comparison of photomicrographs illustrated on page 304, clearly demonstrate this point. At one time it was thought that magnesium acted as a deoxidant in nickel alloys. Now we know that its main function is to counteract the deleterious effects of sulphur. Without knowledge such as this it would be quite impossible to produce on a satisfactory commercial basis, the relatively large and intricate high-nickel alloy castings required today.

New methods have been developed in the foundry to meet particular needs such, for example, as the production of precision castings by investment-moulding methods. New alloys have been evolved to meet modern industrial requirements.

In view of their good frictional properties, tin bronzes, containing around 50% nickel, have long been used in engineering for steam-valve parts operating at temperatures up to 600° F. Within recent years, however, the need has arisen for materials to work in rubbing contact, and without lubrication, at much higher steam temperatures.

TABLE I.—THE EFFECT OF SULPHUR ON CAST MONEL WITH AND WITHOUT MAGNESIUM ADDITIONS

MECHANICAL PROPERTIES	0·05 per cent. Sulpher	
	No Magnesium	0·10 per cent. Magnesium
Max. Strength tons/sq. in.	14·1	32·9
Yield Point tons/sq. in.	13·1	13·4
Elongation per cent. on 2 in.	4·0	35·0
Charpy Impact ft. lb.	16·0	49·0
Brinell Hardness No. (1,000 Kg.)	135	108

Cast Monel, containing around 4·0% silicon, will meet these latter requirements, but due to its high hardness it is difficult to machine and has insufficient ductility to meet all applications. The development, during recent years, of cast graphitic nickel, containing up to 2·0% carbon and 2·0% silicon, may fill a real need for a machinable and ductile material of moderate strength having good frictional properties and resistance to galling at high steam temperatures. Its excellent frictional properties, like those of cast iron, depend upon

Hand tools in spheroidal graphite cast iron made by Robert Taylor & Co. (Ironfounders), Ltd. One is shown twisted through 180° at room temperature.

the presence of graphitic carbon in the alloy, as illustrated on page 305. It is interesting to note that all the carbon in these alloys is present as graphite and this can be controlled to occur in either nodular or flake form as required.

Recently it has been found that additions of titanium have the property of increasing the hardness of cast nickel, without serious reduction of either ductility or impact value. The presence of titanium also makes nickel responsive to age-hardening, and "as-cast" hardness values can accordingly be increased still further by suitable heat treatment. For example, test bars in cast nickel containing 4% titanium, 2% aluminium, when suitably heat treated, have given a 0·1% proof stress of around 35 tons/sq. in., an ultimate tensile strength of 60 tons, and an elongation of around 20%. The most interesting point of all, however, is that the Brinell hardness ranges between 350 and 400, with Izod impact values around 100 ft.-lb. Whilst such alloys are still in the development stage, this combination of properties is truly remarkable for a cast non-ferrous material, and provides a good indication of future possibilities.

Electrodeposition of Nickel

The period under review has seen the establishment of chromium plating with a nickel undercoat, improved methods of testing of the nickel undercoat, development of bright nickel plating, extended application of heavy deposits for industrial uses (especially in the chemical and food-processing industries), electro-forming, improved processing (especially in preparing the basis metal), increasing use of automatic plating equipment, and development of methods for plating on basis metals other than steel and brass, e.g. zinc-base die castings, aluminium and its alloys, stainless steel, etc.

Twenty-one years ago the use of chromium plating for decorative purposes had just become established, and during the ensuing years vigorous attention was given to improving its quality which, in many cases, was not as satisfactory as it might have been. This took the form of improved processing on the one hand and on the other studies concerning the more fundamental aspects. As a result of both research and co-operative study by many interested professional bodies, such as universities, technical institutes, etc., it has been firmly established that the dominating factor in the corrosion-resistance and satisfactory performance of chromium in a wide variety of conditions is the use of an adequate thickness of the nickel undercoat, the amount of which depends on service conditions and on the basis metal.

The B.S.I. has already issued Specification No. 1224, which was intended to cover general plating conditions, but steps are now being taken to provide a similar specification covering the more rigorous conditions encountered in the automobile industry. Coincident with the issue of the specification was, quite naturally, a demand for testing, and, here again, interesting developments have taken place, amongst the most notable of which is the B.N.F. Jet Test for estimating thickness; details of this test are given in the above-mentioned specification.

Perhaps the most interesting development is that of bright nickel plating, the chief advantage of which is the elimination of polishing between the nickel-plating and chromium-plating operations which, in the past, has often been a source of subsequent defective corrosion-resistance in service, due to the somewhat unavoidable tendency of the operator to polish too much nickel off prominences, such as corners, edges, etc. The use of a bright nickel which does not need any polishing ensures adequate thickness at these vital positions. Two main types of bright-nickel plating solution are in use, one of which produces a deposit containing up to 15% cobalt, while the other depends on the use of special organic additives to the solution. Most of these solutions work at a lower pH than was customary with dull nickel, i.e. the pH is usually below 4·5. In order to meet the special requirements of the low-pH nickel solutions the carbon type of anode has been developed: this, on dissolving, forms a carbonaceous film which acts as a filter. The depolarised anode, which has been very popular for many years, was originally developed to provide uniform corrosion and to meet the conditions arising from the use of solutions operating at a pH of about 5·5. Whilst these anodes can be used over the whole plating pH range, they find more favour at the higher pH levels.

Heavy electrodeposition, for building up worn or over-machined components, was already established at the beginning of the period under review, the main process being that of Fescolising. Since that time, the heavy deposits of nickel have also found increasing use in the chemical and food-processing industries, as well as for aero-engine purposes. The use of nickel for reclamation of worn and undersize parts was of tremendous benefit during the war period, and in this connection the Armament Research Department, under the aegis of the Ministry of Supply, issued a comprehensive series of memoranda giving working details. Developments such as the increasing use of zinc-base die casting for various fittings, especially in the automobile, and also the use of aluminium and aluminium alloys, especially in the general hardware field, brought in their train the need for chromium plating, partly for protection but mainly for decorative purposes. Considerable advances have been made, and the position is that both these types of material are now chromium plated with a nickel undercoat and give satisfactory service. Similarly, methods have been developed for the chromium plating of stainless steels, especially where the latter are used for automobile trim and it is desired to match the other chromium-plated parts.

A review of developments in the electrodeposition field would not be complete without mention of the Electrodepositors' Technical Society, which has been in existence for just over twenty-one years. This young and virile society has performed the exceedingly useful function of extending technical knowledge in the plating industry and therefore very considerably improving the standard of the products.

Nickel-Alloy Cast Iron

The period has been one of striking advance in the development, production and application of nickel cast irons. In 1929 the non-magnetic, nickel-manganese cast iron "Nomag" was already in use in electrical plant, and other austenitic irons were being developed. As a result, "Ni-Resist" (nickel-copper-chromium) and later "Nicrosilal" (nickel-silicon-chromium) cast irons came into production; they are used for corrosion- and heat-resisting applications. Simultaneously, the martensitic irons, particularly the nickel-chromium white iron

"Ni-Hard," were also beginning to merit attention, by reason of their marked resistance to abrasion.

The period has seen the use of these special-purpose irons increase to such an extent that to-day there is no major industry which does not employ them for some part of its equipment, and the outlook for the future is one of continued increase.

However, even more spectacular advances have been made in the field of the high-strength, nickel-containing irons. Early in the period under review, the most prominent of these was "Ni-Tensyl," made by addition of nickel and silicon to molten iron of selected base composition. This satisfied the desire of that day for cast iron with tensile strength consistently in excess of 20 tons/sq. in., a stipulation which, in fact, was not covered by standard specification until 1938. As in the case of steels, the introduction of alloys was found to improve the response of cast irons to heat-treatment, and nickel-containing irons, which can readily be hardened after machining, are now widely used.

The development of high-strength alloy cast iron was greatly speeded by the wartime demands for iron castings to replace steel wherever possible. Much progress was made by use of the pearlitic and acicular nickel-molybdenum irons, which opened up many new fields of application for cast iron. This led, in 1941 and 1948, to the issue of B.S.I. specifications for two higher grades, with minimum tensile strengths of 23 and 26 tons/sq in. respectively. In actual fact, however, tensile strengths substantially higher than 26 tons/sq in. were obtainable by suitable heat-treatment of the nickel-molybdenum irons. Nevertheless, these remained flake-graphite irons, essentially non-ductile, despite their high strength and their favourable characteristics.

The more recent developments, so much the subject of current writings as to require no detailed description here, can only be termed revolutionary. By effecting modification of the graphite from flake to spheroidal form, the new techniques have enabled the iron-founding industry to place at the disposal of engineers ductile irons of exceptionally high strength. In this development also nickel is playing a vital part, as the carrier for magnesium, the element most widely employed to achieve this effect. The advent of spheroidal-graphite cast iron is exposing vast new fields for exploration by the iron-founding industry.

Tin and its Alloys

By John Ireland, M.C., B.Sc., Wh.Ex.

Tin has had a long past but the 21 years just elapsed has witnessed notable developments alike in the production of the raw metal and in its uses ; a brief account is given of the progress achieved during the period covered, largely as a result of the close alliance of scientific knowledge and workshop practice.

An important new tin field has been developed in the Belgian Congo where output has grown from under 1,000 tons p.a. to 14,000 tons. This goes far to compensate for the loss of production from Burma, Siam and China where political disorders have interrupted the flow of tin to world markets.

The older producing areas, Malaya, Indonesia, Bolivia, etc., have, however, maintained their rates of output. Steady, though unspectacular, improvements in the art of extraction have extended the area of profitable exploitation to land which would have been deemed valueless twenty years ago. This is particularly exemplified in the case of the tin dredges which have approximately doubled the depth at which they can operate, but it is equally true of drag lines, monitors and other mining machinery, where power used, and efficiency attained, have been substantially increased. The art of recovering the tin ore from the raw output of dredge or mine has also advanced, and it should be remembered that the small particles of tin ore have to be sorted out from about 50,000 times their own weight of alluvial material. Some measure of the advance in this art may be given by saying that under favourable circumstances it is now possible to work ground of only half the tin content looked for twenty years ago. This progress has considerably extended the potential supplies of tin.

A modern tin mining dredge at work in Malaya.

The uses of tin have undergone some striking changes, but as it is consumed in several quite different industries, to give any account of the progress made these have to be reviewed separately.

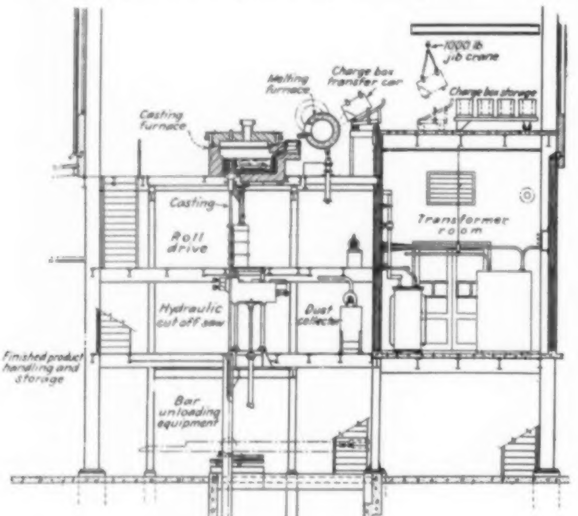
Tinplate

The manufacture of tinplate constitutes the largest single market for tin, accounting for some 40% of annual production. The quantity of tinplate used fluctuates with the consumption of canned foods and with the rise and fall of general productive activities, but, broadly, consumption has increased from three million tons per year to over four million tons although the tin consumed by the industry is now little more than at the beginning of the period. This rather surprising economy arises not through changes in the ultimate consumer demand but through two revolutionary developments in manufacturing technique.

The first change was the adoption of powerful cold reducing mills in place of the hot mills on which the industry had previously depended. This had two effects, it permitted the use of purer steels with lower metalloid contents, particularly lower phosphorus, and it produced much smoother and more uniform steel basis strip. It was quickly found that the new material was more resistant to corrosive attack and that a packaging material of equal virtue could be produced with a rather thinner coating of tin.

The second development was more revolutionary. The raw material was now available in long lengths of strip 30 in. or more in width and in coils several tons in weight. Tinplate had hitherto been made by dipping small sheets into baths of molten tin. A continuous process was obviously desirable, but there were technical difficulties in producing good tinplate by passing a long length of steel strip through a hot tinning bath. The process of electro-tinplating which had been improved by researches in the early thirties offered a practical alternative.

The history of the rapid metamorphosis of electro-tinning research in the thirties to large scale industrial electro-tinning in the forties is almost incredible, and can be explained only by the pressure generated by the desire to save tin, partly on economic grounds but chiefly because of its scarcity during the war years.



Arrangement of equipment for the continuous casting of copper alloy products at the Perth Amboy plant of American Smelting and Refining Co.

The modern mechanism for making electro-tinplate is an imposing structure, occupying a building some 250 feet long and requiring some 50 feet from the top of the upper structure to the basement provided for the electrical and other services. (The looping pits may go down some 50 feet below ground level). The typical electro-tinning line comprises a series of processing units connected in tandem through which the steel strip passes at from 500 to 2,000 ft. per minute. The raw material is bright annealed, temper rolled, steel strip in large coils. The first unit is therefore a decoiler which is designed to feed strip continuously into the mechanisms next in line, which involves welding the trailing edge of one strip to the leading edge of the next. Subsequent units degrease and pickle the strip and pass it to the plating unit proper, after which it is rinsed and flow brightened by a momentary fusion of the tin coating before it is recoiled, and ready to go to the inspecting, shearing and slitting mechanisms.

About thirty of these enormous units are at work in the U.S.A., two in Canada and one at Ebbw Vale. Others are in course of erection at Trostre in South Wales and yet others are projected for France, Belgium, Holland and elsewhere.

By electro-deposition it is possible to apply a closely controlled thickness of tin coating which can, if desired, be much less than that on hot dipped tinplate. A thickness of about 0·00008in. is typical of the hot dipped product; from a half to a quarter of this is common on electro-tinplate. This development therefore produces a more flexible product. It is not claimed, however, that these thinner coatings are the equal of the thicker coatings for all purposes, but there are many uses of tinplate for which they are adequate technically, and of course since they are less costly (if the large tinning units are operated at capacity) they are attractive economically.

Meanwhile, the art of hot dipping has not stood still, although not yet able to utilise broad continuous strip. Sheets can now be fed by machinery into the pickling and hot tinning machines and thence through the cleaning and assorting mechanisms without being handled manually, an advance that goes far to neutralise the disadvantages of the hot dipping process from the manufacturer's viewpoint.

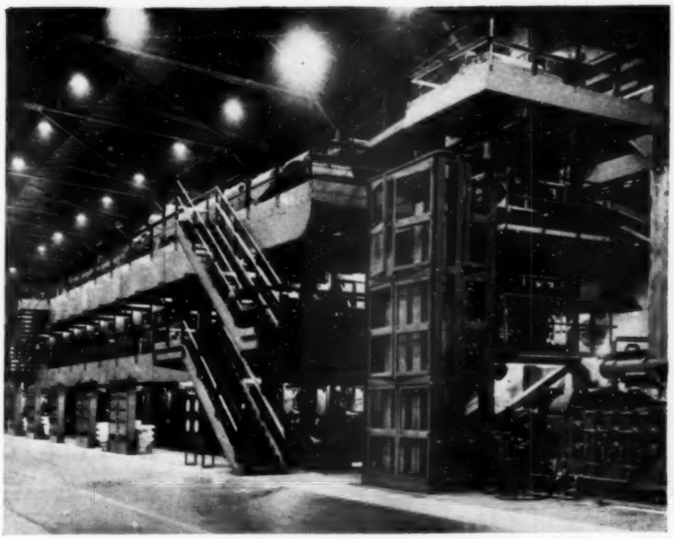
As to the future, the new electrolytic technique provides an integrated, and continuous, manufacturing process which is attractive and profitable to the manufacturer when he can keep his plant working to capacity. Its operation can be regulated and consequently various grades of tin plated sheets can be manufactured. This is undoubtedly an important advance towards giving the user the most economical material for his job. Already probably 90% of the world's tinplate is made from cold rolled strip and 50% is coated electrolytically. It seems likely that technical advances in these relatively new arts will permit still further advances.

Bronze

Bronze is probably the earliest form of metal known to man. It is prized just as highly to-day as it has ever been, but the methods of its manufacture have changed remarkably little until quite recently. The difficulties in manufacture arise chiefly through absorption of gases during the molten stage which are released on solidification and give rise to deep-seated unsoundness as well as

serious surface defects. The trouble is frequently complicated by irregular segregation of some of the constituents. In consequence the proportion of rejects is high and the manufacture of bronzes has been relatively difficult and expensive, hot working is seldom possible, cold working frequently hazardous, and machining less easy than is desirable. For these reasons although the engineering qualities of bronze, its strength, toughness, and resistance to corrosion make it very attractive to the designer, its use has been restricted.

Research in the past decades has uncovered the causes of these difficulties. The correct conditions for melting and pouring are known and a good deal has been done to improve methods of preparing moulds and cores, and when the best known practices are followed a very much improved product is obtained. The adaptation of this recent knowledge to the variety of products and conditions existing in industrial foundries is, however, a process that will take some considerable time.



General view of the electro-tinning line at Weirton Steel Co. The plating section is a triple-decked structure. On the lowest deck the cleaned and pickled strip receives a tin coating on its underface ; it then passes over rollers and travels in the opposite direction over the middle deck where it receives an equal deposit of tin on the reverse face. It again reverses direction passing over the upper deck for electrolytic reclaim and washing.

The most striking development in bronze manufacture is, however, the new plant for the continuous casting of bronze bars and sections which has been erected by the American Smelting & Refining Co. at their works at Barber, N.J., U.S.A. This plant is equipped with electric arc furnaces which discharge their contents into reservoirs where the metal is held under a nitrogen atmosphere. From the reservoir the metal flows directly into a water-cooled die from which it emerges as a solid rod or section of the required shape. An important feature of the set-up is that at no time is the metal able to absorb either oxygen or hydrogen in any quantity. The other feature is of course the relatively slow pouring effect and the very rapid cooling. In consequence the metal freezes from the bottom up, no dirt or dross is entrapped and any dissolved gases are liberated before solidification is complete. A further important consequence is that there is no segregation and constituents, such as lead, which are insoluble in the solid matrix, are evenly dispersed. As a result, the close and even grain structure provides substantially higher impact and fatigue values, while the absence of hard and soft spots speeds up machining. The length of the bars admits of important economies in setting-up time in the machining processes while there is a minimum of scrap arising from short rods.

This plant has now been operating for about three years and the demand for its products fully bears out the claims made for the process. Whether, however, these advantages can be extended to the smaller European markets is still doubtful. The plant units are large and costly and setting-up time is important, which makes it difficult to cope with the variety of sizes and compositions demanded from a European foundry. The new development has shown that improved bronzes are possible and that these will command larger and wider markets, but the problem of making such products on a relatively small scale has still to be solved.

Electro-deposited Tin Alloys

The most novel development in the use of tin arises out of the advances in electro-deposition technique mentioned above. This is the new art of electro-depositing tin alloys. Electrodeposition is a field in which the metallurgist merges into the chemist rather than the physicist, and for alloy plating sound chemical control is indispensable. The alloys obtained in this way have a special theoretical interest as they may differ in structure from similar alloys obtained from the molten phase, and the new technique offers the possibility of making alloys of hitherto unobtainable properties. To date the tin-copper alloy known as Speculum has obtained wide acceptance on account of its attractive silver-like colour and a tin-zinc alloy of about 80/20 composition is coming increasingly into use as a protective coating for relatively mild corrosive conditions. Its ready solderability is responsible for its use on radio chassis and electrical signalling equipment, but it is also used on domestic fitments such as curtain rods, and on bolts and nuts used in automobiles where its good friction qualities may be helpful.

The oldest electro-plated tin alloy is tin-lead. This has long been used as a protective coating on steel as the presence of even a small amount of tin enhanced the corrosion resistance of lead under many conditions. But in recent years quite a large scale use has developed in the manufacture of bearings, where the tin-lead alloy provides a satisfactory running surface. The proportion of tin used for this purpose is around 10% but this quantity trebles the hardness of the lead and stops its corrosion by lubricating oils. Recent developments in plating practice have permitted the plating of an alloy containing substantially more tin and this is being used as a precoating for articles which have subsequently to be dip soldered—car radiators being a case in point—and many others will suggest themselves.

Perhaps, however, the most important development affecting the use of tin in the past two decades is the establishment of the Tin Research Institute which has

been set up by the united efforts of tin producers, in many parts of the world, to provide free technical service to all tin users and to carry out research and act as a centre where all information affecting scientific or industrial progress in the use of tin is collected and made available to any enquirer. The cumulative effect of such an organisation, even apart from new knowledge which it may create through research, is difficult to exaggerate. A typical instance is its impact on the immemorial art of hot-tinning. A study of the practices involved has reduced this empirical art to a series of thoroughly understood steps which can readily be controlled and can be adapted to varying raw materials. The art of soldering has advanced through a more complete understanding of the part played by the various ingredients in the solder and new and improved fluxes have been developed, which combine increased activity with a less corrosive residuum. In bearings and in other uses of tin the principles underlying good manufacturing practice have been established and handbooks of working instructions have been made widely available.

This close alliance of scientific knowledge and workshop practice, not of course peculiar to tin, is an outstanding feature of the past twenty-one years. Its effectiveness, however, is dependent on the contact made by the investigating scientists with the widely scattered consuming public, and its contribution to our industrial progress is therefore closely bound up with the growth of the technical press which does so much to make that new knowledge generally available.

Progress in the Precious Metals

By J. C. Chaston, Ph.D., A.R.S.M., A.Inst.P., F.I.M.

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The precious metals have properties and characteristics that have won for them important applications in industry, it is therefore of interest to consider some of the outstanding developments in the group comprising gold, silver, platinum and the five platinum metals palladium, rhodium, iridium, ruthenium and osmium, during the last twenty-one years.

THE precious metals are commonly considered to comprise gold, silver, platinum and the five platinum metals palladium, rhodium, iridium, ruthenium and osmium. It is not easy to find a common basis for a review of developments in this group of metals as a whole and thus in the space available it will probably be preferable to indicate briefly some of the outstanding developments and trends under separate headings.

Gold

During the last 21 years, the world's output of gold has followed a reasonably steady pattern. South Africa has consolidated its position as the leading producer, no outstanding new deposits have been discovered and no revolutionary changes have been made in the methods of recovering or refining the metal. The volume of gold recovered during this period easily constitutes a record for all time ; in the years 1931–1940 output was 314,935,450 troy ounces as compared with the previous record amount of 206,110,310 ounces in the decade 1911–1920. The outputs of the gold-producing countries of the world in 1937 and in 1940 are compared in the following table :—

	1937 T.ozs.	1940 T.ozs.
North America	9,080,040	11,086,000
Central America	140,036	287,300
South America	1,388,729	1,722,000
Africa	13,990,259	17,069,400
Europe	5,500,221	4,900,000
Asia	2,829,892	3,878,500
Australia and New Zealand	1,811,681	2,273,000
Total	34,742,858	41,216,200

Most of the new gold mined is, of course, shipped to America as bullion, and only relatively small amounts are available for either decorative or utilitarian purposes. As an industrial metal, however, gold would undoubtedly be used more widely if it were more readily available. As it is, its outstanding resistance to oxidation and chemical attack determine the use of gold or gold-rich alloys for such applications as spinnerettes (for artificial silk manufacture), for electrical contacts, for fountain pen nibs, for dental wires, plates and castings, and for the linings of some items of chemical plant. In addition, thin films of gold, applied to glass, have recently been developed for use for optical filters and for airmen's goggles. They remain cool in use since they reflect rather than absorb infra-red radiation.

The gold alloys have not, as a class, received any notable attention during the period under review. The gold-copper system has, however, proved to be of quite outstanding interest as an example of one in which certain alloys show the phenomenon of "ordering." It may, perhaps, be recalled that as early as 1919, Tammann recognised that it might be possible for the atoms of the two metals of a binary simple solid solution to arrange themselves in the lattice so that they formed a regular pattern. If the atoms of the metals are of different sizes, this regular arrangement, as Bradley has written, most usually takes the form of "a regular alternation of atoms of different sizes, big and little, so that the atomic planes will be preserved in their pristine beauty." Such a regular "ordered" arrangement has been termed a "superlattice" and "the ideal superlattice would correspond to a definite composition and would obey the laws of definite and multiple proportions."

The first experimental evidence of the formation of a superlattice was reported by Bain in 1923 as a result of X-ray diffraction studies of the 50 : 50 (by weight)

Fig. 1.—Induction brazing of steering columns at heads with Easiflo silver solder.

Fig. 2.—Large ingot of fine silver. This ingot, weighing 60,000 ounces troy (nearly 2 tons), believed to be the largest ever cast, was extruded to tube for lining chemical plant.

gold-copper alloy, corresponding to Cu_3Au. When an alloy of this composition is slowly cooled, the gold atoms migrate to the cube corners and the copper atoms to the centres of the cube faces of the face-centred cubic lattice. The change is not accompanied by any appreciable changes in the lattice dimensions or by appreciable hardening. Although the fact of ordering of the Cu_3Au alloy was well established 27 years ago, the problems of why the atoms should take up their positions to form this regular pattern and, more particularly, the manner in which they move into their allotted places, have proved of great fascination to metallurgists and physicists alike. Attempts to throw light on these problems have inspired the theoretical studies of Bragg and Williams, the experimental investigations on electrical resistivity of Sykes and Williams, and on specific heat of Sykes and Jones, and many other research projects. The widely-held theory that ordering on slow cooling starts at small stable regions of order (anti-phase nuclei) and that these grow and coalesce, occasional out-of-step atoms being changed round in the process, has developed largely from this work on gold-copper alloys.

Less theoretical attention has been given to the rather different type of ordering shown by the alloy containing 25% of gold by weight, with equal numbers of atoms of the two metals, corresponding to AuCu. In this alloy the ordered structure is such that atomic planes parallel to the base of the original cubic structure are composed alternatively all of gold or all of copper atoms and the change from disorder to order is accompanied by great distortion of the crystal lattice and appreciable hardening. Bradley has, in fact, suggested that the ordering of AuCu is a definite phase change since it really involves a change in the crystal structure from face centred cubic to tetragonal. He distinguishes between the "superlattice" of Cu_3Au and the "superstructure" of CuAu. Harker, however, in a lengthy discussion of the phenomenon, appears to consider the change a typical example of a disorder-order mechanism. Incidentally, no really detailed studies of either the hardness or dilatometric changes during the ordering of AuCu appear to have been published; an omission all the more serious since many dental alloys are hardened by this reaction.

Silver

During the last 21 years, silver has remained essentially a by-product metal. Even in Mexico, which since the 16th century has been the greatest individual producing country, about half the output of silver has come from the lead and copper smelters. At present, only about 20% of the world's silver is obtained from silver ores, about 45% is derived as a by-product from lead and zinc refineries, 18% from copper and nickel refineries, and 15% from the gold fields of the world.

Industrially, silver is becoming of ever-increasing importance. In 1937, concerned by the possibility that with the decline in interest in silver as a coinage metal, production might over-run demand, a group of American silver producers embarked on an ambitious project to exploit silver and develop new uses. The main result of this work was the publication of the excellent volume "Silver in Industry," under the editorship of Lawrence Addicks; but as it happens there seems little prospect that there will ever be any shortage of uses for the metal. During the last war, the American treasury lent this country many hundreds of ounces of silver for industrial purposes and this is being repaid in part with silver recovered from the silver coinage now being withdrawn from circulation (and replaced by cupro-nickel).

Metallurgically, silver is of interest particularly in its reactions with oxygen. Oxygen diffuses through silver far more freely than through any other metal; and silver is the only metal which rejects oxygen from solution on solidification. The most detailed study of the effects of dissolved oxygen on molten silver is that made by N. P. Allen in 1932, who constructed a ternary diagram to illustrate the effects of pressure and temperature on the oxygen-silver equilibrium. Allen's work clearly shows that there is in some ways a similarity between copper and silver in their reactions with oxygen. Normally the similarity is masked by the instability of Ag_2O; but if the pressure over the metal could be increased sufficiently to prevent dissociation of the Ag_2O the resemblance would be very close indeed. Allen showed that under a sufficiently high pressure, silver and Ag_2O form a eutectic melting at 500–600° C.; similar in all important respects with the Cu-Cu_2O eutectic melting at 1,065° C.

In the solid state, oxygen is only very slightly soluble in silver and it has been suggested that above 400° C. it is present in solution in the atomic form while at lower temperatures it is present as Ag_2O. A metallographic study by the present reviewer has shown that oxygen in solution does not influence the grain growth or give rise to the hydrogen embrittlement (on annealing in hydrogen) of extremely pure silver; but that silver containing 0·01% of copper or iron suffers grain-growth restraint when annealed in air or oxygen and becomes embrittled if, after heating in oxygen, it is subsequently annealed in hydrogen. These effects are ascribed to the effects of distributed particles of base metal oxides formed during heating in air by internal oxidation. The whole subject of the internal oxidation of silver alloys is of considerable interest and has been studied by Rhines and Grobe as well as by Meijering and Drayvesteyn and the reviewer.

The most important industrial uses of silver continue to be as a constituent of the engineering silver solders, as an electrical contact metal, as a material of construction for chemical plant and as a catalyst. Reference may be made to an interesting method of brazing developed during the last war for the construction of aircraft intercoolers. The intercooler blocks are built up from copper strip, about 0·008 in. thick, coated with a layer of about 0·00025 in. of silver. When the assemblies are heated in hydrogen to about 800° C. a molten layer of silver-copper eutectic forms on all the surfaces and flows into all joints—uniting many hundreds of joints in one operation.

Platinum and the Platinum Metals

Before 1916, about 95% of the world's platinum came from alluvial sources . . . mainly from the Urals. Since the first great war, however, very little platinum has found its way from the Russian workings into the markets of the world (possibly the deposits have been worked out); and two important new sources of the platinum metals have been developed. The first of these is from the great copper-nickel deposits of Sudbury, Ontario, from which the platinum metals are recovered as a by-product. Although these deposits contain only 0·007 ounces of platinum metals to the ton, it is estimated that 150,000 ounces of platinum could be recovered annually if the plant were worked to capacity. Twenty-one years ago it seemed possible that platinum, like silver, would become a by-product of base-metal metallurgy.

The second source of platinum is also in association with nickel and copper and occurs in South Africa, in the Merensky Reef which forms part of the Bushveld igneous complex, an irregular oval region of 15,000 square miles in the central parts of the Transvaal. The reef extends for several hundred miles along the outer zone of the complex and is particularly rich in platinum

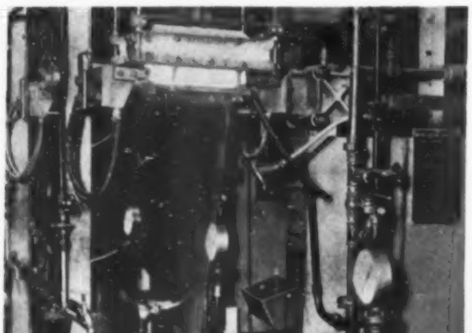


Fig. 3.—Extrusion of glass fibres from platinum trough.

Fig. 4.—Rhodium-platinum gauze, 3 metres in diameter, for use as a catalyst in ammonia oxidation.

in the Lydenburg, Potgietersrust and Rustenburg districts. Most of the platinum exists as the minerals Cooperite (PtS) and Braggite ((PtPdNi) S), occurring in association with chalcopyrite ($CuFeS_2$) and pentlandite ((FeNi) S) in seams in a matrix of norite. Here the deposits are rich enough to be worked primarily for their content of platinum metals; and since 1929 they have been a major source of the world's supply. For a short period, ores were worked from the three districts mentioned above, but since 1930 only the Rustenburg mines have been operated, the average production being of the order of 50,000 ounces of platinum per annum. Recently ,however, arrangements have been made to increase the output very considerably; and it seems likely that platinum will once more be produced to an important extent from primary sources.

The product from the mines is crushed and first concentrated by gravity methods to produce a rich concentrate containing 30–35% of platinum, 4–6% of palladium, 2–3% of gold and ½% of ruthenium and other platinum metals. The tailings are then treated in froth flotation cells and a flotation concentrate containing 10 oz./ton of platinum is obtained; this is smelted to matte and bessemerised to give a product (containing 25–30 oz./ton of platinum, 12–18 oz./ton of palladium, and 5–6 oz./ton of other platinum metals) which is shipped, with the rich concentrates, to this country for final refining.

Technically, one of the most interesting advances in connection with platinum is the development of induction melting methods. The refractory problem has been satisfactory solved, and platinum and its alloys are regularly melted and cast in induction furnaces. Very little research has been reported, however, on the alloy systems of the platinum metals; the most important being the investigations of Wictorin on the thermodynamics of the gold-platinum system. Some interesting observations of hydrogen embrittlement in platinum-ruthenium alloys have been reported by Atkinson and Gladis, with particular reference to its occurrence in gas-welding operations.

One of the most important uses of platinum is in precious metal thermocouples, and the development by Schofield of the quick immersion method for measuring the temperature of a bath of molten steel has had an important influence on steel-making practice in this country and, more recently, in America. In some plants, difficulties were experienced through embrittlement of the couple wires; and as a result of co-operative research the trouble was traced to the effect of traces of sulphur-bearing oil in the assembly which, by an interesting reaction with the silica sheath, could form small amounts of silicon sulphide which attacked the platinum.

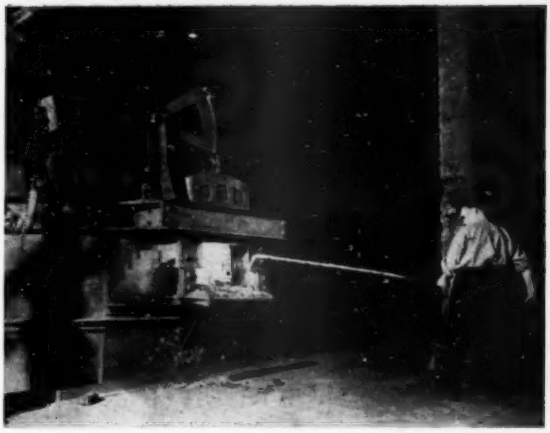


Fig. 5.—A quick-immersion thermocouple (employing platinum and 13% rhodium-platinum elements) in use for measuring temperatures of the steel bath in an arc furnace.

There is space only to make brief reference to other applications of the precious metals. Mention should be made, however, to the use of platinum crucibles for melting iron-free optical glass, platinum containers for melting and extruding glass fibres, platinum-clad electrodes for the manufacture of persulphates, and the growing use of platinum gauze and platinum-coated carriers as catalysts. The outstanding resistance of platinum to corrosion by most mineral acids, by oxygen and by fluorine will undoubtedly lead to its continuing service on an ever increasing scale as an industrial metal

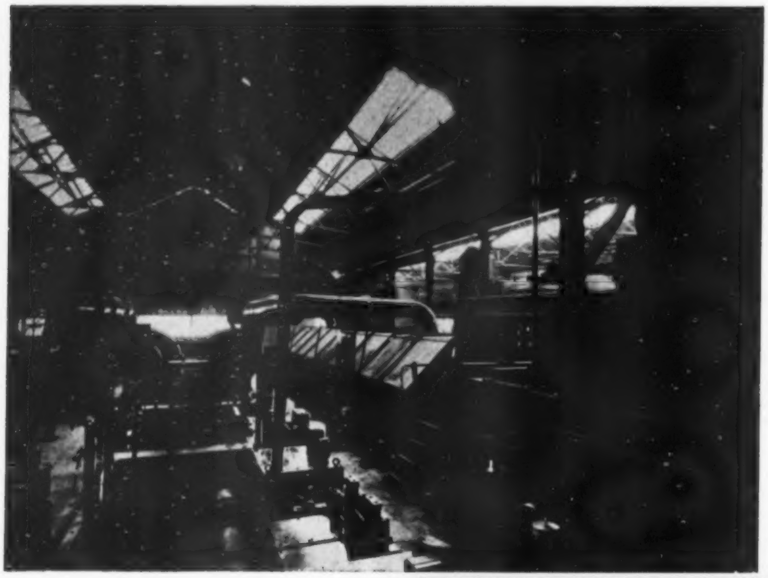
21 Years of Progress in the Zinc Industry

At the beginning of the period covered by this review, total production of zinc in this country supplied about one-third of home requirements. Since then absolute and inadequate equipment have been replaced by two modern plants operating new processes which have increased production considerably. These developments are discussed and attention directed to the increasing usefulness of zinc and its alloys in various industries.

AN assessment of the progress made in the past 21 years in the zinc industry must necessarily envisage conditions in the industry at the datum year 1930.

From the end of World War 1 to 1930 there were nine zinc producing works in Great Britain. The total production of these works was only approximately one third of that which was required for home consumption and therefore the majority of the zinc used in the country had to be imported. The companies were subsidised by the Government, and when, in 1930, the subsidy was withdrawn, there came a major collapse in the industry. The only works left operating were those owned by The National Smelting Co. Ltd., at Avonmouth and Swansea, and also the works operated at that time by the Sulphide Corporation at Seaton Carew. This catastrophic collapse was principally caused by a failure to modernise. During the first World War, larger and up-to-date plants had been built abroad, and the obsolete and inadequate equipment at home was unable to compete.

The Swansea Vale Spelter Co. was in 1924 almost the sole survivor of what had been an extensive zinc industry in South Wales. It was taken over by The National Smelting Co. Ltd., the main subsidiary of Imperial



Sintering Machine

Smelting Corporation Limited. At this time the company acquired the partly completed Government-sponsored plant which had been commenced at Avonmouth in 1916. The plant was completed and the production of zinc there began in 1929. During the 1939–45 war the retort plants at Seaton Carew and Birmingham (New Delaville Spelter Co.) were run for a short time, these are now closed down and all zinc produced in Avonmouth and Swansea Vale works.

The National Smelting Co. Ltd., formed amongst the decay of the South Wales zinc industry was surrounded by ample evidence that, for the zinc industry to survive, not only must the performance of the furnace house be raised to the highest level, but it was equally important to adopt the best method of roasting the concentrates, as well as to utilise the liberated sulphur dioxide to make sulphuric acid by the most efficient method possible. Adoption of new processes had to be immediate as soon as their commercial superiority was proved.

An attempt is made to show how this policy was carried out and how the two plants now in operation have developed.

Concentrates Used

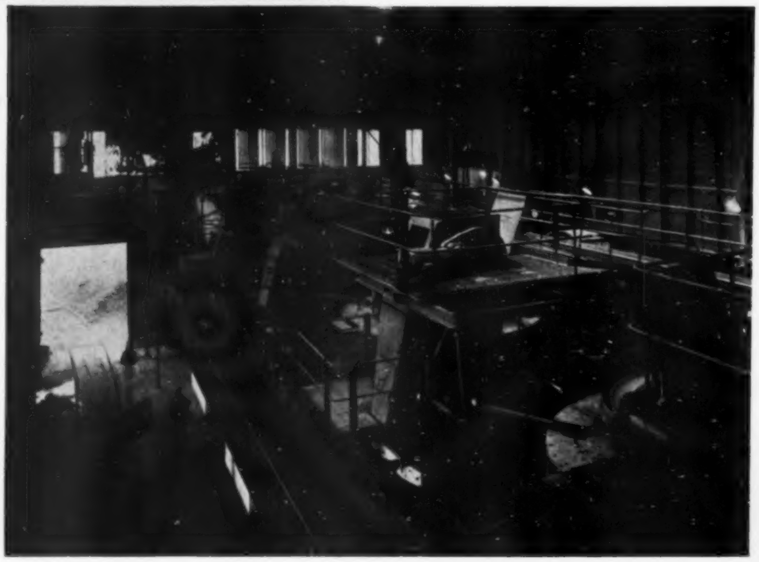
At the present time no zinc ore in commercial quantities is mined in this country and the smelters at Avonmouth and Swansea rely entirely upon imported concentrates. Under normal conditions the major portion of these concentrates come from the Australian Broken Hill mines, the remainder is drawn from all over the world.

These concentrates vary mineralogically. In some, iron is combined with zinc sulphide as marmatite ; in others free iron sulphide is present, with the zinc sulphide occurring as sphalerite. For horizontal distillation the marmatitic types tend to produce less retort corrosion for a given iron content and these are generally preferred. In spite of the diversity of origin and of mineralogical composition the chemical analysis of these concentrates does not vary greatly.

As would be expected from the nature of the flotation process, the concentrates, as received, are in a fine state of division and are taken from covered storage to the conditioning plant, where any agglomerates are broken down, and thence pass by belt conveyor to the roasting plant.

Hearth Roasting

Since zinc sulphide is unattacked by carbon, the first step in the extraction is to convert the sulphide into the more reactive zinc oxide. This roasting operation is an exothermic reaction. While the heat liberated is considerable, it is insufficient in the ordinary type of hearth roaster to support the reaction sufficiently to give complete elimination of sulphur. In such furnaces the reaction tends to ' blow itself out ' as the sulphur content of the blende is reduced below 8%, and additional heat must be supplied to effect complete removal of sulphur.



Charge preparation plant for vertical retorts.

Before 1927 roasting was carried out mainly in Delplace furnaces, in which concentrates were charged into the top of a series of vertically super-imposed hearths and raked manually from hearth to hearth. The bottom hearth was heated from below by coal firing, in order to supply the heat required for the final stage of oxidation. Of this type of furnace the dis-

a vantages were obvious; labour requirements were h gh and coal was required for heating the bottom hearth.

Roasting development at this time therefore had two m ain objects: firstly mechanise the operation to reduce t e costs, and secondly, to produce some degree of a glomeration in order to increase the porosity of the d stillation charge. Attention was therefore directed to the possibilities of the sintering process.

Development of Sintering

At both Avonmouth and Swansea the gases containing sulphur dioxide evolved during the roasting process were converted into sulphuric acid by the contact process. This method was preferred to the chamber process since it enabled strong acid, or even oleum, to be made. It was anticipated that the adoption of sintering would bring many problems to the acid plant superintendent. The higher temperatures developed in the sintering bed would eliminate a greater quantity of impurities and would throw a heavy strain on the gas purification system. The production of a steady gas strength exceeding 4·5% SO_2 demanded smooth running of the sinter machines with a high percentage of operating time.

These problems were tackled systematically. Firstly, the roasting operation was mechanised by the installation of Barrier furnaces. These considerably lowered the labour force required and cheapened the roasting operation. In 1927 a straight line Dwight-Lloyd machine was installed at Avonmouth and by using a mixture of Barrier pre-roasted material, efficient roasting was effected. The suphur content of the roasted cake was reduced below 1% and a gas containing 5% of sulphur dioxide was evolved. Simultaneously, modifications to the acid plant and process were made. Efficiencies of conversion to sulphur trioxide of about 98% were obtained.

The roasted material produced by the sintering machine was in the form of a biscuity cake, differing entirely in physical structure from the dense powdery output of the Delplace furnaces. When fed to the horizontal distillation furnaces an immediate improvement was realised. The present output of these same furnaces (288 retorts) is 10 tons of zinc per furnace per day.

Development of Blende Sintering

The next step in the improvement of the Avonmouth and Swansea roasting practice was the development of a method which would dispense with the Barrier furnaces and enable the whole roasting operation to be carried out on sintering machines.

The sulphur content of most concentrates treated is in the order of 30%. To reach, but not exceed, the critical heat liberation of 20,000 C.H.U./sq. ft. of grate area per hour, the sulphur content of the feed must lie between 5 and 6%. This could be realised if the ore feed was mixed with five times its weight of crushed output sinter before feeding to the machines. Tests showed that this was possible and in 1935 the practice was adopted. Hearth furnaces were then discarded and all roasting carried out on sintering machines.

At both Avonmouth and Swansea Vale a uniform type of machine is used. The pallets forming the grate on which the charge rests are 78 in. wide and 39 in. long. The total pallet area under suction is 410 sq. ft. The raw blende is mixed with five times its weight of crushed sinter, and water is added to raise the moisture content to 5 to 6%. The mixture is spread evenly over the bed to form a layer 5 to 5½ in. deep on the moving pallets. The charged pallet passes over a succession of windboxes where suction is applied to maintain combustion.

At the end of the machine, roasting is complete and the cake discharged as the pallets pass over the tip end. The cake, in which the sulphur content has been reduced to approximately 0·6%, is fed to crushers and screens.

Discharging hot briquettes from cokers.

Charging vertical retorts with coked briquettes.

14% is selected for output and the remainder passes to the bins at the head of the machines to be mixed again with green concentrates and resintered.

Recovery of Other Values

The high temperature reached causes vaporisation of most of the compounds more volatile than zinc oxide. Some of these condense on pallet bars and are removed by a rapping device. An elaborate system of electrostatic precipitators and wash towers is used for gas purification. This trouble is repaid however, since the dust and sludges so caught contain by-products such as lead and cadmium which are recovered and treated at Avonmouth. At the cadmium plant (which produces some 150 tons a year of metallic cadmium) further concentration is made and metallic arsenic and metallic thallium are produced in small but profitable quantities.

Horizontal Distillation Process

At both Avonmouth and Swansea Vale, horizontal furnaces are used. Avonmouth also operates the more recently developed vertical retort, which is described later.

In the former type of furnace the retorts are arranged in horizontal rows along each side. The furnaces are producer gas fired and equipped with regenerators. Hot producer gas and air, preheated to 980° C. rise up past the retorts and down past the rows on the opposite side, thence out via regenerators and waste heat boilers to the stack. The passage of air and gas is reversed every 20 minutes.

The retorts are made from carefully selected clays in potteries attached to the distillation plants. Each retort is 67 in. long and has a capacity of $2\frac{1}{4}$ cu. ft. of charge, producing on an average 78 lb. of metallic zinc per day. Each section of a furnace contains 96 retorts.

The furnaces are operated on a 24 hour cycle and when all the residues from the previous day's production have been removed, they are re-charged. The charge consists of 100 parts of sinter and 30 parts of anthracite coal together with the appropriate quantity of old condensers. This is moistened down to a suitable consistency and then charged by hand into each retort. The whole length of each retort is filled to uniform density, this is essential for good distillation. When charged, the condensers are clayed into position and "prolongs" 3 ft. long are fitted, which retain most of the zinc escaping as zinc dust or "blue powder."

During operations full heat is applied to the furnace. The gas evolved begins to burn at the mouth of the condenser. After approximately one hour the characteristic colour of burning zinc appears at the edge of the flames and the gas in the furnace is reduced to give a temperature of about 1,050° C. Metallic zinc starts to collect in the condenser and the distillation cycle commences.

Success depends upon the skill of the foreman controlling the furnace during the remaining 18 hours of the cycle. He must raise the temperature progressively to 1,370° C. in order to maintain the reaction at a constant rate, but the rate must be controlled carefully to achieve maximum efficiency of distillation without damage to retorts.

In view of the considerable part manual labour plays in the operation of the horizontal process every attention is paid to ease conditions in front of the furnace. Cold air is circulated and also movable hoods are fitted to all furnaces. These shield much of the heat radiated from the furnaces during stirring out and charging operations.

The Vertical Retort Process

The horizontal process possesses several obvious disadvantages. In spite of every effort to improve the conditions there is a heavy demand upon a considerable labour force. It has stoutly resisted all the attempts at mechanisation and has, in consequence, the handicaps of a batch process with high labour requirements.

Several expensive but unsuccessful large-scale attempts to develop a mechanical continuous process of distillation have been made. Three main problems required solution: a new method of retort construction with a high rate of heat transfer was necessary; a charge capable of maintaining its high porosity throughout the whole distillation cycle with no formation of slag was essential; an efficient condenser of greatly-increased capacity had to be developed.

These problems were intensively studied by the New Jersey Zinc Co., in the late 1920's and were solved in a remarkably short time. In 1933 a plant to their design was erected at Avonmouth.

One of the main features of the vertical retort process is the preparation of the charge which enters in the form of briquettes. The sinter received from the roasting plant is carefully crushed. Bituminous coal, crushed in hammer mills, has an important function, since, on coking, it must provide the fabric of the briquettes supporting the particles of ore. Owing to the high zinc content (60 to 62%) of the sinter used, crushed anthracite is added in small proportions as a diluent.

The crushed materials are fed at controlled rates to a mixer where the binder is added. From the mixer the charge is fed to the first of three chasers. Their function is that of plasticizers and they do not effect much further crushing. They de-aerate the mix and ensure uniform blending of the constituents.

The mix is fed to 'prepress' rolls, the purpose of which is to give preliminary densification. The prepressed mix then passes to the main briquetting rolls. These rolls produce a pillow-shaped briquette 4 in. long by $2\frac{1}{2}$ in. wide and 1 in. thick—dimensions chosen to give the maximum heat transfer in the retorts.

The briquettes are elevated to the cokers, a certain amount of air drying taking place on the way. The cokers are vertical shafts with perforated walls. Hot waste gases from the retorts are drawn horizontally across the cokers and heat the briquettes as they descend. Rapid coking occurs and the briquettes are withdrawn at the bottom into hoppers carried on "larry" cars, at a temperature of 750–800° C. The hot briquettes are elevated to the top of the building, weighed and then charged into the retorts.

The vertical retorts at Avonmouth are built up of carborundum brick. The retorts are 7 ft. 3 in. long and 1 ft. wide internally. The heated side walls fit into glands in the end walls which alone are tied into the furnace setting. The heated portion inside the furnace laboratory is 28 ft. high. The side walls are $4\frac{1}{2}$ in. thick and are not tied to the setting in any way except at the ends and although heated to temperatures exceeding 1,300° C. have a life of approximately three years. This is an excellent performance, in view of the fact that they are also subject to internal abrasion, due to the passage of some 16,000 tons of charge during this period.

Continued on page 3̇2

The Aluminium Industry 1929-1950

By Col. W. C. Devereux, C.B.E.

The aluminium industry has made great progress during the period under review. In 1929 Britain's contribution consisted mainly of a few relatively small specialised firms or small departments of larger firms, all carrying on their various processes in a rather secretive way. To-day, it is a great and important basic industry supplying vital material used by almost every branch of engineering. Indeed, were it not for the shortage of raw material the demand would ensure a greatly increased production.

As my part in this celebration of METALLURGIA's twenty-first birthday, my good friend the Editor, has set me the task of reviewing the progress of the aluminium industry during the past 21 years. At the same time, he has, perhaps wisely, set a limit on the space allocated to me, which effectively prohibits any attempt at a detailed history of the fortunes and technical achievements of the industry through these years. It seems to me, therefore, that the best way to tackle the assignment is to compare the industry as it was in 1929, in a few important aspects, with the condition in which it finds itself to-day.

The year 1929 was the peak of the post-war boom. In the 1914–18 War aluminium had first come into general use as an engineering material and world production had been increased from 80,000 tons to over 200,000 tons. By 1929 it had increased to about 280,000 tons. In that year U.K. production was about 10,000 tons and our consumption 30,000 tons—we were already heavily dependent upon imports of primary metal. In the second World War, a huge expansion in world production and use took place, reaching nearly 2,000,000 tons in 1943. U.K. production, in that year, was 55,000 tons and the output of its fabricating industry was 271,000 tons, the difference being supplied by imports of primary metal from Canada and, a powerful new factor—the secondary aluminium industry, which in that year produced 88,000 tons of aluminium alloys (actually the peak rate of fabrication, sustained for a brief period in 1943/44, was about 360,000 tons).

In the first six months of 1950 U.K. primary aluminium production was at the rate of 30,000 tons a year (war-time plants with a capacity of about 25,000 tons were dismantled after the war as uneconomic), secondary production was at the rate of 84,000 tons and the output of the fabricating industry was about 230,000 tons. Since then fabricating capacity has been considerably increased by a new rolling mill of 60,000 tons capacity and still further capacity, reported to be a further 60,000 tons, is nearing completion. At the same time demand has increased enormously in the past two months. Were it not for the shortage of raw material, which I will deal with later, we should be in a happy position.

What are the other principal differences between the aluminium industry of 1929 and that of to-day? In 1929 aluminium was a relatively unknown material. To-day no metal except iron is produced in greater volume or is more commonly used in the equipment of our homes, public buildings, factories, and vehicles. In 1929 aluminium was a relatively expensive material. To-day it is about the same price as it was then, while the prices of other non-ferrous metals have increased thrice and fourfold. But perhaps the greatest change of all, is in the status of the industry itself. In 1929, this country's aluminium fabrications industry consisted of a few small firms or small departments of larger firms, all carrying on their various processes in a rather secretive way. To-day it is a great and important basic industry supplying vital material used by almost every branch of engineering.

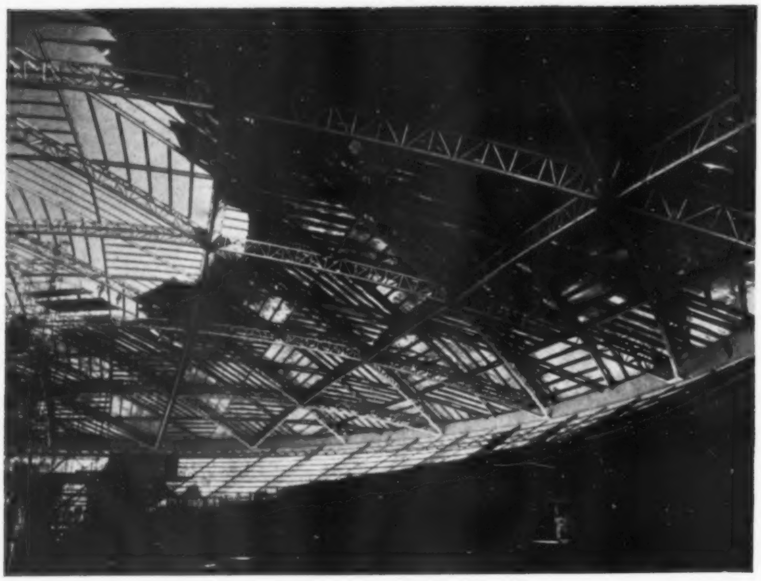
In 1929 the Supermarine–Rolls Royce seaplanes won the Schneider Trophy races and from this time the U.K. aluminium industry became closely associated with the growth of aviation and devoted most of its technical resources to the task of meeting the demands of the aircraft designers and engineers for higher strength materials of greater reliability.

Technical developments in this country, from that time until 1943–4, were therefore, dictated mainly by the search for high strength at normal and elevated temperatures and the highest possible standards of quality practically regardless of cost. This was achieved by very close scientific control of production processes and the highest possible degree of technical craftsmanship. Compared with to-day's complex management problems those of the early thirties seem very simple indeed—the chief concern was with quality and production. We left the other great potential markets for aluminium to be developed by others.

However, when in 1945, we had to revolutionise our marketing policies to keep working a vastly expanded capacity and our production changed over from ultra high-strength aircraft alloys to durable alloys for structural and other peaceful applications, we were not found wanting in technical knowledge.

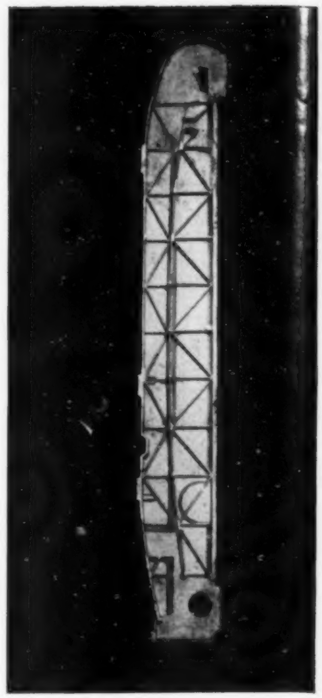
Since the war a high proportion of our output of extrusions has been in the Mg_2Si alloys which before had been produced here in only very small quantities. We are inclined to regard these alloys as being of Swiss or American origin, which, from the development point of view they are, but it was here, at the National Physical Laboratory during the first war, that the fundamentals of the Al–Mg_2Si system were first determined by Rosenhain and his co-workers—a team on whose work so much of our present knowledge and techniques are based.

Looking back now one sees that although a vast amount of scientific data on aluminium was amassed in an astonishingly short time, it could not be fully utilised in practice because we lacked the modern means of interpretation and there were few men available with the right combination of scientific training and industrial experience to apply it. Nevertheless, although in the



Courtesy of Almin Ltd.

The photograph shows the main aluminium structure of the Dome of Discovery in the Festival of Britain before the 2½ acres of roofing was completed. The main arch ribs with an unsupported span of 342 ft. are seen resting on the ring girder with the rafters and purlins in position. Below the ring girder can be seen the girders and purlins of the apron structure. In all some 232 tons of aluminium alloy extrusions and sheet are used in this structure.



Courtesy of Renfrew Foundries Ltd.

Typical of the larger aluminium alloy castings made since the war is this adjustable chain beam for a Wadkin Tenoner machine. The casting is 14 ft. long and weighs 364 lb. The use of aluminium alloy for such applications reduces floor loads and permits long overhangs without loss of rigidity.

twenties and early thirties we progressed largely by rule-of-thumb methods, we did, in the circumstances, make comparatively rapid progress.

It was a great time for inventors. Hundreds of patents were taken out covering aluminium alloys containing practically every known element in every possible combination, and yet, notwithstanding the complaints of the engineers generally, about the number of specifications, relatively few alloys were actually produced in large volume. Chief among these were Duralumin, brought here and developed by Clarke and Aitcheson, Y alloy invented by Rosenhain, the Rolls Royce alloys, and Birmabright, so vigorously developed by the late Percy Pritchard.

With practically virgin markets to develop there was very vigorous competition between the producers of the various alloys and in the struggle to prove the advantages of each alloy over its rivals, resort was made to an astonishing variety of special testing machines and the engineers were assailed with a huge volume of facts and figures and, as has been said unkindly, figures that looked like facts.

They were exciting days and what we lacked in scientific knowledge we made up for with enthusiasm and hard work, gaining vastly in experience. That, on the whole, the work was well done is proved by the high reputation the industry enjoyed for quality and reliability and by the fact that our materials and techniques were followed throughout Europe and laid the solid foundations on which our industry is so firmly based to-day.

Not only has the fabricating industry expanded greatly during these 21 years but it has changed very considerably in structure and scope. Until the early thirties more than half the output was in the form of castings and the greater part of the remainder was sheet and strip.

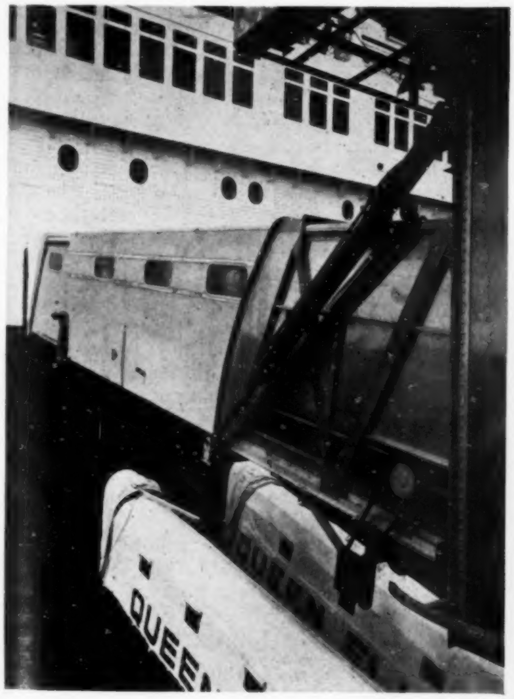
Extrusion and forging of aluminium alloys were undertaken on a very small scale. Previously such sections and tubes, as had been used, were produced from sheet and strip—the former by folding or drawing and the latter by drawing from blooms made by deep drawing sheet circles through as many as eight separate operations on a vertical press—each draw requiring a different set of tools.

The general adoption of the extrusion process had a profound effect on the industry, although, at first, opinion was sharply divided as to the suitability of extruded bar for forging and rolling stock. Some manufacturers put all their ingots through the extrusion press to provide bar for rolling, forging and even for subsequent re-extrusion into sections and tube blooms; others refused to use extruded stock at all, on the grounds that its grain size was erratic and that it could contain flaws impossible to detect by the methods then available. The introduction of the continuous casting process for ingots, of new methods of detecting internal flaws, and a vast improvement in the technique of extrusion has long since resolved these controversies.

Although forgings in pure aluminium and some of the soft alloys were made in the very early days of the industry, the forging of high strength alloys was one of the latest arts to be developed. Starting modestly with the drop stamping of aero-engine pistons it advanced

very rapidly and by 1930 radial engine crankcases were being produced by drop stamping and by pressing in hydraulic presses. Forged propellor blades followed, and connecting rods ranging from those for small automobile engines to railway locomotives. It was in the Bristol radial engines, however, that strong aluminium alloy forgings found their widest scope. So limited was the equipment of the industry, in the early days, that some parts travelled hundreds of miles from one plant to another between operations. It was largely on account of aero-engine requirements that the light alloy forging industry was expanded in 1939–43 to a capacity of 40,000 tons a year. Its present output of less than 5,000 tons a year shows how specialised was its market.

The end of the War found the industry faced with a vast new array of problems. To many, the chief among them was the problem of creating sufficient demand to employ the vastly increased capacity as built up during the war. However this problem was not, in the event, so formidable as it had seemed. The reasons for this were due to the greatly increased engineering experience of aluminium, the shortages of other materials, the greatly increased efficiency and scope of aluminium fabrication and, the relative stability of the price of aluminium compared with the rapidly increasing costs of other engineering materials.



Courtesy of S.M.D. Ltd.

One of the six telescopic gangways designed and constructed by Structural & Mechanical Development Engineers, Ltd., for the new Ocean Terminal at Southampton. These gangways, mounted in three units each consisting of a shore housing and a pair of gangways, provide fully enclosed passenger ways between ocean liners and the first floor of the terminal. They can be slewed, luffed, telescoped and extended to a total length of 68 ft. The total weight of each unit is 17½ tons.

In 1929 the aluminium was £107 a ton. In 1930 it fell to the lowest pre-war figure of £85. Then for six years from 1933 to 1938 the price remained constant at £100 and it was under the influence of this constant price in a world of fluctuating metal prices that much of the soundest basic development work was carried out.

After the War, during which the Government had become the sole dealer in aluminium at a fixed price of £110 a ton, there was a rapid fall to an all-time low of £67 10s. a ton for a brief period in 1946. Since then the price has risen gradually, mainly in step with various economic crises, until to-day it stands at £120, the highest figure since 1925. However, this increase is much smaller in proportion than the general advance in the prices of other non-ferrous metals.

Despite its great resources and its importance in the engineering economy of this country the aluminium industry has its Achilles heel—its dependence on overseas supplies for the bulk of its raw material. For many years the bulk of our imports of virgin aluminium have come from Canada and, indeed, the Canadian producing industry has been built up largely in step with our fabricating industry. Until 1947 this arrangement worked very well indeed. Then came the dollar crises and with it the fear, which has persisted ever since, of serious cuts in aluminium supplies. Since early 1948 the fabricating industry has been rationed to about 186,000 tons of aluminium a year. Apart from this Government restriction on quantity and its attendant necessity to limit the use of aluminium products, the handling of supplies by the Ministry of Supply has been well and fairly handled (except for some rather unimaginative attempts to restrict end uses) and the long-term contracts it has made with the Canadian producers has ensured a reasonable and comparatively steady price for the metal. Nevertheless, the industry would be unanimous in saying that it would have been

Courtesy of Pressoturn Ltd.

The fish market at Grimsby is completely equipped with 30,000 fish boxes of the type illustrated. The introduction of these containers has considerably reduced the cost of replacement and repair. Because they do not absorb fish slimes and moisture the aluminium boxes have a low and constant tare weight and are much more hygienic for the handling of fish. Other fishing ports are similarly equipped.

better to have stood a price increase in order to secure greater supplies so as to ensure continuous economic production.

The present re-armament programme here and in the U.S. have now precipitated a further crisis for our industry. Production of aluminium in the U.S. is unable to keep up with the demands of the re-armament programme, Government stockpiling and the very large domestic demand. There is, therefore, a very strong U.S. demand for Canadian aluminium which naturally conflicts with our own requirements. We can only hope that, between them, the Canadians, Americans and our own Government will reach a solution which will enable us to keep on fabricating aluminium.

This question of supply is thus the great question mark in the future of the aluminium fabricating industry. Technically, aluminium seems about to enter a great new era of large-scale engineering application. The fabricating plants have sufficient capacity to meet immediate demands and the capabilities of the material have been clearly demonstrated by such major prototypes as the Dome of Discovery, the Arvida Bridge, the Southampton Gangways and a thousand and one successful applications ranging from fish boxes to transportable townships. Shortages will not last for ever and in any case ambitious plans are in hand for new aluminium production plants in the sterling area. The long range prospects are bright if only the industry can survive the next five critical years.

Looking further ahead, the growth of the industry will depend very largely on the steady development of its manufacturing resources, improvement of its technical processes and above all on increasing efficiency and reducing costs of production.

The pursuit of these objectives will make heavy demands upon our managements, research workers, and engineers. We must increasingly mechanise and improve the efficiency and range of our fabricating plants, we must find better methods of manufacturing and assembling aluminium components and structures. Such developments will take a long time and will absorb a great amount of capital, which may be difficult to find, but we must give our full attention to these things if we are to be ready to meet the increasing demand which will arise as the cost of aluminium falls in relation to that of other engineering materials.

A revolution in the economics of aluminium production may not lie so very far ahead. Very encouraging experimental results are being obtained in thermal production processes and, looking further ahead, there is the promise of the development of a new source of very cheap power in the atomic research now being so vigorously carried on with practically unlimited resources.

Expansion in the Use of Aluminium

By Dr. E. G. West, B.Sc., F.I.M.

In 1929 applications of aluminium, apart from its use in aircraft, were just developing, but during each of the last few years production has exceeded the total output up to the year 1939. This great expansion has been helped by technical progress in the production of goods and the establishment of aluminium in new fields; it is on these aspects that the author bases this review.

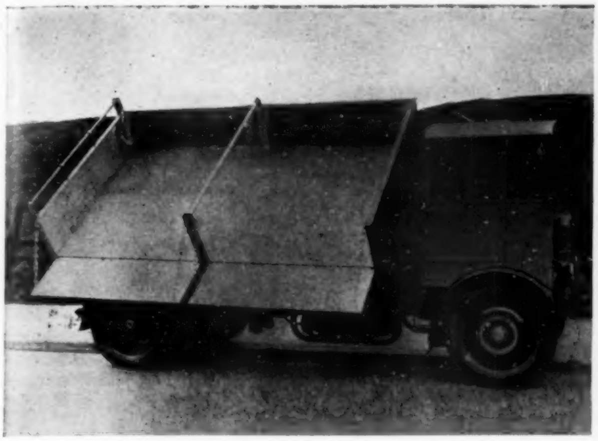
DURING the past 21 years developments in aluminium have been by far the most spectacular, both among the metals and almost all other industrial materials. World output of primary aluminium in 1929 was of the order of 290,000 tons, whilst to-day it is running at some 1¼ million tons. Indeed, output during *each* of the past few years has exceeded the total output of all the years since aluminium was first produced commercially, until 1939. It is worth stressing these figures because the present high output was not greatly exceeded during the peak years of the War, so that although aluminium owes some of its unprecedented expansion to war-time demands, the continuing high production figures of the past 5 years are an indication of strength in peace. This expansionist tendency bids fair to continue with little or no break, unless rearmament or economic factors beyond the control of the aluminium industry interfere.

Aluminium in Great Britain has been, and remains, in the forefront of world development and the British industry has contributed much to the solution of the problems faced by this country. Thus, direct exports of aluminium are now 12 times greater than 12 years ago, and the contribution to the general rehabilitation of the country is well illustrated by the adoption of aluminium for houses and other building purposes on a scale unparalleled elsewhere.

The great expansion in the use of aluminium during the 21 years under review has been both helped by, and has assisted in, important technical advances in aluminium fabrication. These twin aspects—technical progress in the production of aluminium goods, and the establishment of aluminium in new fields—are interdependent and cannot be completely separated in the present survey.

In 1929, aluminium was just developing along lines not directly concerned with aircraft, with which it had been closely tied as a result of the first World War. The needs of the aircraft industry both for wrought and cast aluminium alloys continued to claim a great deal of attention from the industry and these demands increased as 1939 approached. This had its effect on the equipment used in the industry, particularly for sheet and strip, sections and forgings. A very high proportion of the output was in the form of heat-treated high strength alloys for aircraft, with comparatively little production of the so-called common alloys. Following the end of the War in 1945, there has been a considerable change in the output, non-heat-treatable material increasing steadily, particularly for sheet.

A review of the main fields of application is followed by brief notes on some of the advances made in technique and production to the benefit of users and potential users.



Courtesy of the Duramin Engineering Co., Ltd.

Aluminium alloy 3-way tipper, built in 1933. Left—the vehicle as built originally, and Right—the same lorry 16 years later after the floor plates had been renewed after 11 years' service.

Road Vehicles

Dealing first with some of the older uses of aluminium it is interesting to recall that road vehicles have, since the earliest days, used aluminium engine castings and also aluminium sheet for bodywork. With the coming of the pressed-steel, flash-welded motor car body, the amount of aluminium used fell, but from 1929 to 1939, there was a steady increase in the amount of light metal in commercial goods vehicles where the basis of taxation and speed restrictions favoured the extensive application of aluminium to this class of vehicle. During the same period, aluminium became increasingly important in 'buses and coaches, but these developments were interrupted by the War. Since 1945, they have again moved forward until the use of aluminium in road vehicles is, to-day, some 20% of the total. During the War, vehicles continued in use long after their normal allotted span, with minimum maintenance, and this was a particularly searching time for engine and chassis components. It is especially interesting that very few failures of aluminium alloy components were encountered, and the report of progress made by a specialist builder in a recent Symposium[1] provides valuable confirmation of the long term value of aluminium in goods vehicles. For specialised containers and vehicles for particular purposes, aluminium alloys have been long used and have now been adopted on a large scale for quantity produced lorries, 'buses and coaches. In private cars the traditional aluminium panels on ash frames have continued for the high-price, custom-built cars, but the use of pressed aluminium alloy bodies, doors and wings, has expanded, and aluminium figures in this country and abroad in a number of well-known medium and low-priced models.

Electrical Applications

Another early use of aluminium—electrical conductors—has continued to make progress in both H.T. overhead cable and busbars. Another most important step was taken in this country within the last three years when aluminium was successfully applied as a cable sheathing material in place of the more usual lead. More than one method of making aluminium-sheathed cable is already being exploited here on the commercial scale. Allied to this development may be noted the now extensive use of aluminium conduit, junction boxes, switch cases and electric motor castings.

Building

In 1929, the use of aluminium in building was almost confined to decorative features in public offices, etc., but during the next 10 years, progress was made in the manufacture of aluminium alloy window frames and glazing bars, and there are now many examples of each after many years satisfactory service. A small amount of aluminium was also used for a few specialised roofing purposes. These applications have given confidence in the more extensive post-war use of aluminium for entirely new building uses, such as rainwater goods, roof trusses and wall cladding.

The most outstanding development is, undoubtedly, the pre-fabricated aluminium bungalow[2] which not only still represents the most extensive use of aluminium for building anywhere in the world but also provides the outstanding example of true pre-fabrication applied to the production of houses. This successful bungalow encouraged the use of aluminium for other portable dwellings and for the pre-fabricated schools which are not only helping to provide the extra places required in Great Britain but are also being exported.

Rainwater goods represent another entirely new outlet for aluminium and the British Standards[3] for wrought and cast types indicate the measure of acceptance which they have found among architects, builders and property owners. This is a good example of a shortage of the conventional materials allowing aluminium to be tried, with a minimum of opposition, and the metal's advantages have so justified its adoption that it should remain a permanent field for aluminium.

Structures

Allied to building is the growing interest in aluminium for structural purposes—again a Post-War development. During the period from 1929 to 1939, a few structural applications in aluminium were brought to fruition, particularly crane jibs and dragline booms where the reduction in weight so improved efficiency that the extra initial cost was fully justified. It is, however, doubtful

Courtesy of the Triumph Motor Co. (1945), Ltd.

The Triumph Roadster, shown for the first time at the 1950 Paris Salon d'Automobile, has a double skinned body of aluminium alloy and represents one of the most notable advances both in car design and in the use of aluminium for this purpose.

Courtesy of the Rover Company, Ltd.

The Land Rover, in the construction of which a great deal of aluminium alloy is used to give valuable reduction in the weight of a vehicle designed for hard service in rough country.

if it was foreseen in 1929, that before 20 years had elapsed, more than one aluminium bridge would be in constant use. The repair of the Smithfield Street Bridge at Pittsburgh in 1934, by the use of aluminium marked an important step[4] but the opportunity afforded by reconstruction at the Port of Sunderland in 1948, to include an aluminium bascule bridge, marked a new advance, and more recently the 500 ft. span bridge at Arvida has been completed.

A field closely allied to building and structures is that of contractors equipment, including small tools and lifting appliances. The best known example is the very successful aluminium alloy scaffold tube which has been wholeheartedly accepted by all concerned. It is regrettable that perhaps world shortage of aluminium will adversely affect the progress still being made in this and similar applications.

Marine Applications

World-wide application of aluminium in marine work has taken place during the past 21 years and the principal developments have been almost entirely carried through in this country. Around 1930, the late Percy Pritchard began his now well-known full-scale experimental use of aluminium alloys for small boats, and a number of the craft built from 1931 to 1935, still in service, are widely regarded as valuable exhibition pieces to-day. The first ship's lifeboat in aluminium-magnesium-manganese alloy, in 1934, was the prototype for a long line of lifeboats which are becoming accepted as standard by the world's shipping industry. Many hundreds in use have convinced many shipowners of the twin virtues of saving top weight and reducing the cost of protective measures against the elements. Vessels of all types from 6 ft. dinghies to 140 ft. cruisers, tested and used in all parts of the world, have encouraged builders and owners of big ships to adopt aluminium for superstructure and internal fittings of their vessels.

Aluminium for stressed superstructures was being explored during the late 1930's and the fundamental approach by Muckle[5] has notably contributed to the application of light alloy to all types of vessels from cross channel steamers to Atlantic liners. Muckle's initial work has been followed by investigations in America, and the issue by Lloyd's Register of Shipping of "Tentative Rules for Aluminium Alloys for Shipbuilding Purposes" marked a decisive stage.

A further significant step was taken by the aluminium industry itself when plant was laid down and techniques perfected for the production of thick alloy plates in the sizes required by shipbuilders. Recently, practical tests have been completed in shipyards on the forming, flanging and general handling of aluminium alloy plates and sections, so that the time is virtually ripe for the consummation of all this research in a stressed all-aluminium alloy superstructure for a large vessel. There is no doubt that shipbuilding is potentially the biggest single market for aluminium—a tonnage market worthy of all the attention the aluminium industry has given, and is still devoting, to it.

The fishing industry has also taken advantage of aluminium with many vessels fitted with aluminium-lined fish-holds ensuring that the catch is landed in the best possible condition. The success of aluminium here, is now leading to its further adoption in other parts of trawlers and the advantages of the alloy fish hold have been duplicated by using aluminium boxes to convey the fish to the shops.

A more recent development still is concerned with barges ranging up to the 1,500 ton-types for carrying goods on the great rivers of the world. The merits of aluminium for pre-fabricated barges for shipment to distant countries and their consequent re-erection by local labour is particularly important.

Railways

There has always been considerable interest in the use of aluminium on railways, but progress has been slow. It is interesting to recall that in the 19th century, the Russian Government of the day ordered a number of aluminium railway wagons but, unfortunately, there is no record that they were ever built or used. Interest has greatly quickened during the past 20 years and on the Continent a number of aluminium rail vehicles built during the 1930's survived the War. During the past five years, both America and Europe have again begun building aluminium coach and goods stock, and in this country new London Underground Tube coaches are under construction in aluminium alloy.

Mining and Fuel

Early in the period under review, several mine cages were built for use in deep South African mines, but little further development was undertaken in mining equip-

ment until recently, and the first all-aluminium pit cages for coal mines have now seen more than a year's satisfactory service. Tubs and trucks of various sizes have been installed and many other items of equipment ranging from shovels and hand tools to electrical equipment, conveyors and skips, have been developed in aluminium. The savings in power and man-hours in handling lighter equipment are contributing to increased coal output and it can be expected that this application will grow.

Interesting work on a smaller scale, has been undertaken in Ireland, where aluminium is being applied to peat winning machinery and plant. This again is in its initial stages and represents a market based on the particular fitness of aluminium for this rather exacting duty.

The oil industry is another fuel producer in which the value of aluminium is now being explored. Finally mention must be made of the most up-to-date energy producer—the atomic pile—for various parts of which aluminium has again proved suitable.

Agriculture and Food

In agricultural and horticultural equipment, aluminium progress has been slow, due in part to the unfavourable economics involved, for agricultural implements provide one of the most competitive industrial markets. However, in spite of the desire to keep initial costs to a minimum, aluminium is being used for certain equipment, such as grass dryers, seed planters, parts of silos, and tractors. Greenhouses, cold frames, irrigation systems, and many items such as plant propagators and garden labels are new uses of interest to the amateur and the professional horticulturalist.

In dairy farming, aluminium has been more widely adopted for utensils, drinking bowls, milk churns, and in a few cases, complete milking parlours. The higher first cost of aluminium is fully justified by its longer life and this outlet for the products of the aluminium industry should expand as long as the farming industry can allow a fair proportion of capital expenditure to be undertaken.

Nearer to the ultimate consumer of the farmer's products, the use of aluminium for packaging is due for considerable expansion. The value of aluminium as a packaging material has been recognised for many years, but progress during the 30's was slow, due chiefly to the entrenched position of tinplate available in quantity at a relatively low price. This has changed during the past few years and aluminium, allied to new techniques, is establishing itself firmly as a packaging material.[6] Much of the material produced in the new rolling mills installed by the aluminium industry will find its way into packages of one kind or another.

It is in packaging too, that aluminium has entered into some interesting partnerships with other materials, such as plastics, and some useful aluminium foil-plastic laminates are now widely accepted. There is no doubt that the uses of aluminium foil have expanded both for packaging and as an insulating material and when metal supplies are more plentiful foil usage will undoubtedly increase to several times its present figure.

Several aspects of the fabrication of aluminium deserve at least passing mention in a review of the period in question, and in particular advances in casting, extrusion and rolling on the one hand, and joining processes and finishing methods on the other.

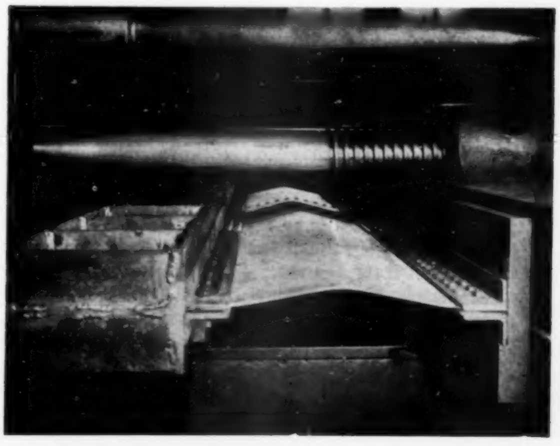
Specifications

There has been great development in the alloy field including a remarkable increase in the effective utilisation of scrap. This has led to the very desirable but difficult formulation of Standards to cover many of the aluminium materials in use.

The producers of wrought products have employed ever-increasing quantities of process scrap in their melts and the availability of large quantities of scrap of all kinds has been one of the most important economic factors affecting the aluminium industry during the last five years as well as during the War. Much of the scrap arising from obsolete and crashed aircraft and other war equipment has been dealt with by the specialised light alloy refiners and to-day ingot material is accepted as being equal to virgin metal for the majority of purposes. Specifications prepared by the industry, by Government departments and by the British Standards Institution have taken full account of the importance of using scrap metal efficiently and the sources of scrap are almost as

Courtesy of Saunders Engineering & Shipyard, Ltd.

M.T.B 539, the first coastal force craft in aluminium throughout.

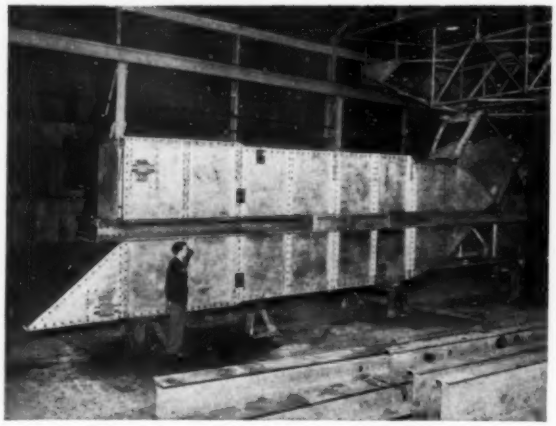


Buckling test on aluminium-5% magnesium plates with riveted joints. These tests form part of the investigations by Muckle.

important to-day to the aluminium industry as scrap iron is to the steel industry.

The overall progress made in standardisation during the 20 year period, particularly recently, is of the utmost value in development work and there now exists a complete range of British Standards for ingot, castings and wrought products for General Engineering Purposes, as well as the specialised standards required by the Service Departments in particular for aircraft. It is generally admitted that a further measure of simplification would be desirable, but there is doubt as to whether the time is yet ripe for reducing the number of standard materials available to the engineer.

Parallel to the adoption of Material Standards there has been built up a considerable number of specifications for aluminium products. One of the best known examples is B.S. 1161, covering standard sections, and other items for which British Standards now exist, or are in final draft form, are cast and wrought rainwater goods, sinks and many other household items, welding electrodes and scaffold tubes.



Courtesy of Rhymney Engineering Co., Ltd.

10-ton skip installed in a British coal mine. This is of aluminium alloy and steel construction using alloys NS.4 and HS.10.

Casting

Casting falls into two main parts, namely :—the production of cast rolling slabs or extrusion billets, and the production of sand or die-castings. In each branch there have been many improvements in the equipment employed for melting and handling the metal in the foundry, and control has greatly improved too.

The problems of ensuring melts free from gas which gives rise to porosity in castings was under investigation about 20 years ago and culminated in the several methods of degassing now practised commercially. The work of Hanson and Slater, of the N.P.L. investigators and of the B.N.F.M.R.A. is well-known and to many it will be something of a surprise that these research results came into use within the last 20 years.

In the production of slabs and billets for subsequent fabrication, the outstanding advance has been in the adoption of semi-continuous casting with which has been associated the availability of very much larger slabs. The changes within the period may be gauged from the fact that slabs may now weigh more than 10 times the largest in general use 10 years ago. Continuously cast metal is much more free from porosity than chill cast and in general the structure is finer.

Rolling

The casting of rolling slabs by the continuous process has led to consequential changes in the technique of hot rolling, and reference should be made to the various papers published recently[7] on these aspects. Finally must be mentioned the great importance to future development of the availability of large plates, up to 30 ft. by 6 ft. by 1 in. thick.

In the use of rolled sheet and strip for new applications several problems requiring a solution have been brought forward, such as the tendency of some aluminium alloys to give stretcher-strain markings when subject to forming operations, especially in motor car body work. Investigations on this and other problems are still in hand, although it is too early yet to give results.

Extrusion

Extrusion of aluminium is also undergoing considerable changes and the admirable paper by Smith[8] on the subject well summarises the present position. Many of the advances made in the art and science of extrusion of aluminium are set out in this paper, and again one of the most important development aspects is the much larger section now being produced compared with 20 years ago. The demands of the aircraft designer and of other users have necessitated the installation of larger and more powerful presses. Furthermore, a great deal of metallurgical research—much of it on the works scale—has been carried out especially directed towards the development of extrusions free from the tendency to large grain size and with more uniform structures. Extrusion speeds have increased and one of the most important advances is the quenching of heat-treated alloy sections at the die. The product is satisfactory and shows mechanical properties at least as good as those of separately heat-treated stock. Multi-hole dies yield economies in production, but again their introduction has required a great deal of investigation to establish satisfactory practice. Further versatility has been given to the extrusion process by the development of the port-hole or bridge-die which involves fundamentally the pressure welding of two or more parts of the section in the die itself.

Joining and Finishing

Structural developments, together with the extensive work on marine applications, have thrown up many problems on which investigations have been carried out. Foremost among these has been the manufacture and driving of large aluminium alloy rivets to allow rivets greater than $\frac{3}{8}$ in. diameter to be used, i.e., larger than those required in aircraft. All the problems have not yet been solved, but good progress has been made both in this country and in Canada, and large rivets are now being successfully employed.

The welding of aluminium structures has not advanced by the same amount, although valuable results have allowed recommendations to be made, for example, by Sir Donald Bailey,[9] which could not have been put forward a few years ago.

There has been a great increase in the weldability of aluminium and its alloys both by the fusion and the resistance welding processes, and the developments of cold pressure welding and of brazing constitute major

Courtesy of Johnson & Phillips, Ltd.

Electric power cable sheathed with aluminium represents one of the latest advances and is an all-British development.

advances. Spot welding equipment and flash welding machines for aluminium have been largely developed within the last ten years, and the biggest single contribution to joining has been the argon-arc welding process.

In 1929, the adoption of anodic oxidation had scarcely begun anywhere in the world, but in the next 10 years it was established as a valuable commercial process, and in the last 10 years it has made still greater strides. For example, continuous anodising of strip is commercially practised and there is now a British Standard (B.S. 1615) covering the performance of anodic oxide coatings.

Finally, may be mentioned the new applied finishes devised for aluminium, of which the etch-primer and the vitreous-enamel-type glaze may be specially noted.

1 A.D.A. Symposium on Aluminium in Road Transport, 1950. See paper by E. L. Oglethorpe, pp. 15–27.

2 A.D.A. Publication "The First Factory-Made Aluminium Bungalow," 1948. See pp. 13–20.

3 B.S.1430: 1947. Aluminium Rainwater Goods, Cast and Extruded. B.S.1543: 1949. Wrought Aluminium Rainwater Goods.

4 Smithfield Suspension Bridge, Pittsburgh. *Engineer*, 27th July, 1934, pp. 91, 93.

5 W. Muckle.—Some Considerations in the Application of Light Alloys to Ship Construction. Trans. North East Coast Institution of Engineers and Shipbuilders, Vol. 60, 1943. W. Muckle.—Application of Light Alloys to Superstructures of Ships. Trans. North East Coast Institution of Engineers and Shipbuilders, Vol. 62, 1946, pp. 329–60. W. Muckle.—Resistance to Buckling of Light-Alloy Plates. Trans. North East Coast Institution of Engineers and Shipbuilders, Vol. 64, 1948. W. Muckle.—Experiments on a Light Alloy Model Superstructure. Trans. North East Coast Institution of Engineers and Shipbuilders, Vol. 65, 1949, pp. 413–450.

6 Dr. E. G. West. The Place of Aluminium in Packaging. *Metallurgia*, February, 1950, pp. 204–208.

7 F. Kasz and P. C. Varley. The Hot Rolling of Aluminium and Its Alloys. *J. Inst. Metals*, 1950, **76**, (5) 407–428. E. Scheuer.—Modern Billet Casting with Special Reference to the Solidification Process. *J. Inst. Metals*, 1949, **76**, (2), 103–120.

8 C. Smith. The Extrusion of Aluminium Alloys. *J. Inst. Metals*, 1950, **76**, (5), 429–451.

9 D. Bailey. Light Alloys. *J. Inst. Civil Eng.*, October, 1950, 279.

Magnesium and Magnesium Alloys 1929—1950

By F. A. Fox, D.Sc., M.Sc., F.I.M.

Although the production of magnesium in 1929 *was small, with Germany predominant in its technology as well as production, the commercial application of magnesium alloys was in active development, however several problems were awaiting solution. An increase in the use of the metal justified the erection of a production plant in* 1935 *and as a result of more intensive research very considerable progress has been achieved.*

READERS of the technical press have become accustomed to frequent statements that the light alloys are our newest engineering materials, and that their rapid development has been in large part due to a considerable research effort. These are well-known generalities, taken to apply to both aluminium and magnesium. The full appreciation of such statements, however, requires some appraisal of the status of the material as it once was, in comparison with that of the present day. For both the light metals the changes have been considerable, and in order to help review advances in the magnesium field, an outline will be given of the situation as it appeared 21 years ago, in 1929.

Magnesium Technology in 1929

At this time, Germany was very much the world centre not only of knowledge of the technology of magnesium and its alloys, but also of production. There was then no magnesium manufactured in the U.K. on any commercial scale; although there had been production by Messrs. Johnson Matthey at Woolwich during the 1914–1918 war, it had ceased in 1918. In 1929 U.S. production was of the order of 300 tons; although French production units were in existence, their output was small. German annual production was of the order of 1,000 tons, a considerable proportion of which was being exported to England in the form of alloys for engineering uses.

Although these figures are small, the commercial application of magnesium alloys was in fact in active development. Only seven years before, in 1922, the first patent covering the casting of magnesium alloys in greensand moulds had been taken out (D.R.P. 384137); in 1924, the first casting license agreement with a British firm had been concluded with Messrs. Sterling Metals, Ltd., Coventry, while in the following year, the first rolling mill for magnesium alloys was established at Rackwitz, near Leipzig. In 1925 also, the first tests on pressure die-casting of magnesium alloys had been made.

Only three years previously, in 1926, the world production of magnesium had been about 300 tons; however, during the period 1925–1929, the I. G. Farbenindustrie A.G. and its predecessor, the Chemische Fabrik Griesheim-Elektron, had been developing the process for the production of anhydrous magnesium chloride from magnesite, and the successful completion of this task stabilised production methods and made possible reductions in production costs.

During this same period, A. Beck had announced in 1926 the discovery that manganese, as an alloying element, had a very beneficial effect on the corrosion resistance of magnesium alloys. This method of improving and controlling corrosion performance constituted a considerable technological advance, and in the same year a D.T.D. specification was granted in this country (D.T.D. 59) for a magnesium casting alloy containing aluminium, zinc and manganese.

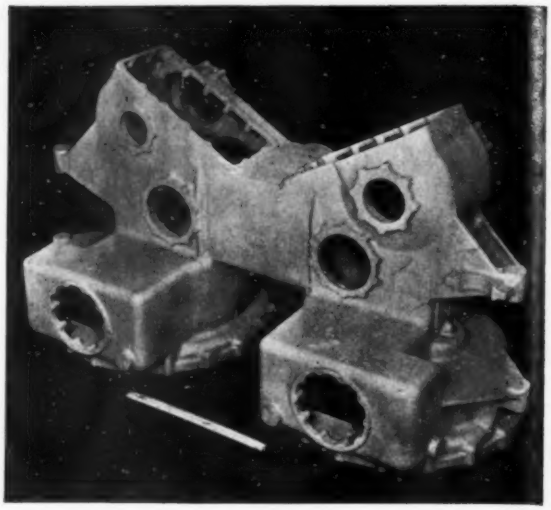
A filip to the development of magnesium alloys in this country had been given by provisions of the Finance Act of 1928, which called for the licensing of motor transport vehicles by weight. As a result, vehicle manufacturers sought to reduce weight, and a considerable demand was experienced for magnesium alloys for such parts as gear-box bodies, back axle casings and even crank cases.

One may summarise the metallurgical position by saying that in 1929 there was only one magnesium alloy of any importance available in this country. This was that conforming to D.T.D. 59, and which usually contained about 6% aluminium, 3% zinc and 0·3% manganese. It was a casting alloy, produced in Germany and made available by the enterprise of C. J. P. Ball and his company, Messrs. F. A. Hughes & Co., Ltd. The only other alloy of any practical value was the magnesium-manganese binary named Elektron AM503, which carried at that time 2 to 2½% of manganese; this alloy was available as sheet and as extrusions. However, it was imported from Germany only in very small quantity. The D.T.D.59 alloy was available either as castings made in Germany, or imported as ingot and made into castings by the British licensee foundry at Coventry. At that time aircraft demand was not of any importance commercially.

The quality of the castings made in the D.T.D.59 alloy was generally good, although the founders often had considerable difficulty in the form of a high internal rejection rate in achieving this result. The mechanical properties as sand-cast were of the following order:— 0·1% proof stress, 5 tons/sq. in., ultimate tensile stress 10 tons/sq. in., and elongation on 2 in., 4%. Properties of this kind were obtained only in material of a sufficiently fine grain-size; this in turn was obtained only by a grain-refinement treatment the mechanism of which was completely obscure. This procedure was the so-called super-heating treatment in which the melt was deliberately heated to a high temperature of the order of 900° C., held at that temperature for an appreciable time, and then cooled more or less rapidly to the casting temperature (760°–780° C.) and poured without delay.

Although commercial applications were making progress, there were a number of more or less difficult problems awaiting solution and on many of which, there was serious lack of knowledge. Among the most important disabilities were the relatively low strength of the casting alloy, and its temperamental behaviour in the foundry, especially where pressure tightness was concerned. Another difficulty, often aggravated by being unrecognised, derived from the tendency of the casting alloy to be notch sensitive. This factor, sometimes combined with a persistence in downright bad design detail, or an imperfect appreciation of what constitutes good design for light alloys, led more than once to disappointing failures under test. There was also a serious lack of detailed information on the mechanisms of corrosion behaviour, and of the fluxing procedures for the melt, which had been empirically developed, but which were imperfectly understood and gave occasional trouble.

If the problems of 1929 were formidable, the research effort put out in many centres was considerable, both in the technological and scientific spheres, and the effort mounted rapidly as the war years approached. In 1931, Messrs. James Booth & Co., Ltd., of Birmingham, were granted a licence of the German techniques for rolling, extrusion and forging of magnesium alloys, and the same year saw the foundation of the U.S. Magnesium Development Corporation and the taking over of the German patents in France by the Société Générale du Magnesium.



Courtesy of Hobbs Transmissions Ltd. and Firth Helicopters

Fig. 1.—Casting by Messrs. Sterling Metals, Ltd., of Firth helicopter dual rotor drive casing in Elektron Z5Z alloy. Weight 65 lb.

During the next few years, appreciation grew that lack of pressure-tightness in castings was due to solidification shrinkage effects (microporosity), and as experiments were made with other casting alloys in the Mg–Al–Zn system, it became clear that the 3% Zn in the D.T.D.59 alloy was not advantageous from this point of view. Two other alloys became established for the foundry; these were known as Elektron A8 and Elektron AZ91, the former with 8% Al, 0·4% Zn and 0·2% Mn, and the latter with 9·5% Al, 0·4% Zn and 0·2% Mn. These alloys had good founding characteristics, and, being heat-treatable, permitted higher mechanical properties to be reached; for example, as fully heat-treated, Elektron AZ91 would give figures of about 7·5 tons/sq. in. for 0·1% proof stress, 17 tons/sq. in. for ultimate tensile stress, and 1·5% elongation on 2 in.

By 1935, British sales of magnesium and magnesium alloys were at a rate of about 1,200 tons per annum, and the erection of a British production plant seemed justified. A company, Magnesium Elektron, Ltd., was accordingly formed, and with German help a plant was erected near Manchester, which went into production in December, 1936, with a capacity of 1,500 tons of magnesium per annum. This plant was almost immediately extended under Government sponsorship, and by 1938, the plant had a capacity of 4,000 tons per annum.

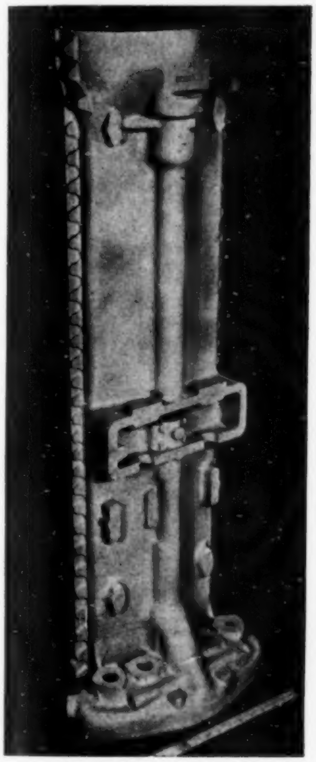
In 1936, Messrs. Murex also began production of magnesium in Britain, operating a thermal reduction process, using calcium carbide as reducing agent.

The starting point for the production of magnesium is magnesia, and this was normally obtained by calcination of Grecian magnesite. However, it became clear that a domestic source of supply would be more attractive both economically and strategically, and co-operative work was undertaken on the production of magnesia, suitable for conversion into metal, from dolomite and sea-water. This work had a successful issue, and the first supplies of magnesia for magnesium extraction were recovered from dolomite and sea-water (which contributes its 1% $MgCl_2$), in 1938.

The War Years

The war years were full of effort, both in research and in the extension of productive capacity. Before passing to an examination of the fruits of the former, a glance at the latter may be of interest.

World production of magnesium ingot was about 30,000 metric tons in 1939, of which about 14,000 came from Germany, 5,000 from the U.K., and about 3,000 metric tons from the U.S. With the outbreak of war, magnesium became a strategic material, needed not only for aircraft parts, but for incendiary bomb cases and as powder for tracers and flares. Great expansion schemes were put in hand, and by 1943, the corresponding figures for Germany, the U.K. and the U.S. were about 32,000, 19,000 and 167,000, with an estimated world production of about 239,000 metric tons. Thus, in about four years, world production had multiplied by about eight, and U.S. production by about 55; the productive *capacity* of the U.S. had, in fact, multiplied by about one hundred. These U.S. figures indicate a rate of expansion unprecedented in the whole metal industry; even the U.K. factor of about four is far from discreditable, particularly in comparison with the German factor of little more than two. In the attempt to spread the effort needed for this great increase, and because of a shortage of electricity supply, various production methods were employed; pride of place was, however, given to the most thoroughly established process of electrolysis of fused magnesium chloride melts, and in the event the electrolytic method turned out to be the most useful. In this field much experience was fortunately available from the Manchester plant, and this was used in helping to guide the U.S. expansion, in the course of which a unit was erected in the Nevada desert which, of itself, had nearly double the capacity (56,000 tons p.a.) of the whole world in 1939. The other processes employed were mostly thermal ones in which magnesia was reduced under appropriate conditions of temperature and pressure. Although, in general, these processes were not so successful, they were by no means all failures and some, the Pidgeon process in particular, had in fact certain real advantages. Experience of these processes also led to distinct advances in the techniques of large-scale vacuum distillation which have been usefully applied to the extraction of other metals.



Courtesy of F. A. Hughes & Co. Ltd.

Fig. 2.—Casting by Messrs. Sterling Metals, Ltd., of De Havilland top cover for Gipsy Queen 70 engine in Elektron AZ91. Weight 29 lb.

Parallel with this massive and pioneering work on the production of the metal, much alloy investigation went on during and after the war years, in its way equally arduous at times, aimed at the improvement of mechanical properties at room or at elevated temperatures, at greater ease of handling in the foundry or hot-working mill or at better resistance to corrosion. At the same time work continued to explore and improve further the general utility of alloys of the known type in the Mg–Al–Zn field.

As a result of the last mentioned phase of the work, the causes underlying the formation of microporosity are now well understood, and fine grain can be induced in casting alloys of this type without the need of superheating—it has been discovered that a treatment with some suitable carbon compound free from oxygen will produce the same effects at 750° C. without raising the temperature to 900° C. The corrosion behaviour of alloys of this type can now be greatly improved by holding the impurities, especially Ni and Fe, to very low limits (the former should be below 0·001%). Heat-treatment behaviour is also much more clearly understood.

Fig. 3.—Castings by Messrs. Sterling Metals, Ltd., of heavy vehicle rear axle cover in Elektron C alloy. Weight 11 lb.

Courtesy of F. A. Hughes & Co. Ltd.

Recent Developments

But this further development of the older known alloys, interesting though it is, is rather small beer compared with the search for entirely new alloys with new combinations of properties. The alloying elements

on which interest now centres are zirconium, cerium and lithium. Of these, there is the smallest body of information about lithium, since it has only recently attracted serious attention. The research work at present being done on the magnesium-lithium alloys is especially interesting since it owes its origin to theoretical considerations rather than to the empiricism which usually operates. Hume-Rothery and co-workers found in 1945 that with an addition of only about 10% by weight of lithium the alloy formed had, like lithium itself, a body-centred cubic structure. This structure is in marked contrast to that of magnesium, which is hexagonal close packed. The inference that alloys in this composition range would be of a ductility higher than that ordinarily expected for magnesium alloys has proved justified, and experimental alloys based on the Mg–Li system appear very promising for good hot and cold working characteristics combined with low density (about 1·6 g. per c.c.), and good strengths. Difficulties remain with these alloys, important among which are the price of lithium, the attainment of the necessary purity in the lithium (it must, for example, be free from sodium), and the provision of special and expensive flux covers.

The two other alloying elements, zirconium and cerium enter jointly into the modern development of the magnesium base alloys, though by far the more important part is played by the zirconium. A detailed description of the development of the magnesium-zirconium-zinc and magnesium-zirconium-cerium alloys is not possible here; accounts have already been given by C. J. P. Ball[1,2,3] and by E. F. Emley[4]. Zirconium exerts an intense grain refining effect on magnesium, the maximum *effective* concentration being about 0·7% by weight. This effect is obtained without superheating and is so strong as substantially to eliminate grain-size variations due to differences in cooling rate in different parts of the solidifying alloy. Part of the difficulty which originally lay in the path of this development was that of ensuring uniform and reproducible addition of the alloying element in the appropriate form without the introduction of accompanying complications, such as flux-inclusions. Having achieved this result, experimentation with third elements showed that with about 4·5% Zn, for example, considerably improved mechanical properties could be obtained, especially after heat treatment. For example, D.T.D. specification 721 which covers this alloy, calls for a 0·1% proof stress of 8·5 tons/sq. in., an ultimate tensile strength of 15·0 tons/sq. in., and an elongation on 2 in. of 3%; 0·1 proof stress figures of 10 tons/sq. in. (just double the 1929 proof stress figure) are in fact regularly obtained. Foundry experience extending over several years has shown that this alloy (Elektron Z5Z) is much less prone to microporosity than the alloys of the Mg–Al–Zn type, and that local strength figures in a casting (cut-up tests) conform closely to those obtained from separately cast test bars. This alloy is also a considerable improvement as far as notch-sensitivity is concerned, and in fact under some conditions of test it shows no notch sensitivity (fatigue tests with a stress concentration factor of about 2).

The addition of cerium (or more strictly, rare-earth metals in the form of mischmetall) to magnesium alloys is no new thing, but in combination with the small grain size of the zirconium containing alloys it has led to a real advance in creep resistance at temperatures up to 200° C. and even somewhat higher, coupled with good foundry characteristics. The alloys concerned contain about 0·7% zirconium and 2·5 to 3·0% cerium, with or without 2·5% zinc. These alloys have good castability, are reliable in the foundry, and at 200° C. are equivalent in performance to the aluminium alloy RR50.

Although the casting side is by far the more important, the zirconium containing magnesium base alloys have led to interesting developments in the wrought field Here again the fine and uniform structure of the alloys seems to be decisive, and these alloys are far more workable than was ever thought possible for magnesium base alloys. Not only can heavy reductions be imposed, but the finished wrought product has again higher mechanical properties than the wrought alloys of the Mg–Mn or Mg–Al–Zn types. With these alloys it is even possible to get away from the necessity to forge hydraulically—so long regarded as the essential technique for magnesium—and to succeed with drop-stamping processes. The alloys can be rolled at speeds and will yield sheet recoveries which are similar to those for pure aluminium.

As compared with 1929, when there was one established casting and one wrought alloy, magnesium can now claim six thoroughly tried casting alloys, and four wrought alloys. The effect is naturally to increase very considerably the versatility of magnesium alloys. Of the six casting alloys, three contain zirconium, and, being the highest duty materials of the group, tend to find their way into aircraft applications, often for major structural parts, e.g. landing wheels. The cerium in two of those three alloys fits them especially for high temperature duty, and it is not surprising to find them playing an important part in jet aircraft engines. The other three alloys are of the older Mg–Al–Zn type, and tend to find non-aircraft applications, such as in the transport and textile industries. Alloy C (the commercial alloy) is, for example, very successfully used for major parts of the engine of the Ferguson tractor.

In a short review of this kind it is not possible to consider in detail the applicational experiences since 1929, and it is preferable to pass to a short discussion of problems still outstanding: one may, however, still summarise the engineering uses of magnesium as being those in which the reduction of weight or inertia is of major importance. Specialised applications based on some specific chemical or other property of magnesium may always of course arise; one of these which is assuming increasing importance at present is that in which magnesium anodes are made to give cathodic protection to steel structures; here the conditions are arranged so that any corrosion which the steel structure would experience is transferred to a renewable magnesium piece which acts as anode under the corrosive conditions concerned.

Future Development

What are the ways in which magnesium alloys will continue to develop? What is required in the metal to give it further development potentialities?

First there is the price consideration. The alloys have already won wide acceptance and a large body of engineering experience has now been built up. Every penny per pound off the price is bound to be reflected in

Continued on page 352

1 Ball, C. J. P., *Metallurgia*, **35**, 206–7, January and February, 1947.
2 Ball, C. J. P., *Chem. and Ind.*, **34**, pp. 531–536, August 21st, 1948.
3 Ball, C. J. P., Paper H.1.11, Fourth Empire Mining and Metallurgical Conference, July, 1949.
4 Emley, E. F., *J. Inst. Met.*, 1949, **75**, 481–512.

Progress in Heat Treatment in the Last Twenty-one Years

By P. F. Hancock, B.A., F.I.M.
Chief Metallurgist, Birlec Limited

The period under review has seen the introduction of a number of new heat treatment processes, while parallel advances have taken place in the equipment for the carrying out of both these new processes and those previously established. Some aspects of these developments are discussed in this article.

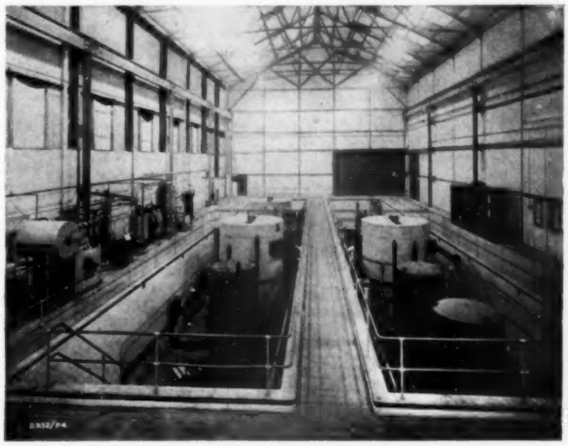
AT the beginning of the period under review, heat treatment furnaces were, generally speaking, crude both in construction and operation. Little attention was paid to automatic controls in any form, and reliance was placed mainly on the furnace operator to exercise his skill in producing the desired results. Solid fuels were much used on the score of cheapness, and there was little mechanisation, furnaces being mostly of the plain open batch type, often hand charged. There were few types of continuous plant in operation, since heat-resisting alloys, having sufficient high temperature strength for the construction of reliable furnace conveyors and other mechanisms, were not sufficiently developed. Scaling of the charge undergoing treatment, and in the case of carbon steels decarburisation, were accepted as inevitable concomitants of most heat treatment operations; in the few cases where it was impossible to tolerate them, resort was had to packing in boxes with charcoal, cast iron borings, or other appropriate material.

Contrasting this picture with that obtaining to-day, the most notable advances apparent in furnace construction are, firstly, in the provision of greatly improved temperature distribution and of fully automatic temperature control, secondly, in the widespread use of controlled atmospheres to preserve the finish of the material treated or to effect some desired change in structure while avoiding the use of packing, and thirdly, in much increased mechanisation. With regard to the last point, the emphasis to-day is on reduction of manual labour to the minimum, and on elimination as far as possible of the human element. As a result there is a tendency also to more specialisation, equipment often being tailor-made to its one specific application. There has been a trend away from solid fuels, as being incapable of adaptation to the required degree of control, and towards the increased use of gas, electricity, and for some purposes oil, as the heating medium.

Some quite new heating methods have been introduced of which, the most outstanding is high frequency induction heating; others which were already in small scale use, such as molten salt baths and electric resistor furnaces, have come to full development in this period, with greatly extended fields of use.

Of fundamentally new heat-treatment processes developed since 1929, there is the whole range of treatments arising out of the original work of Bain and Davenport on constant temperature transformation in steels. These include cycle annealing and spheroidising, austempering, martempering and other variations of the delayed-quench technique.

Some new surface hardening processes have been introduced, for example induction surface hardening, while others, such as cyaniding and nitriding, have



Courtesy, Electric Resistance Furnace Co., Ltd

Fig. 1.—Installation of bell type furnaces

passed from the development stage to full industrial use. Other new processes have arisen from the substitution of controlled atmospheres for the packing processes formerly in use, examples in this category being gas-carburising, and gaseous annealing of malleable castings. In the non-ferrous field, there has been an extension of age-hardening processes; originally developed in connection with aluminium alloys, their application to other groups has proceeded, as suitable alloy compositions have become known.

These are some of the aspects of heat treatment developments during the last twenty-one years, which will be discussed in the succeeding sections of this article.

Temperature Control and Distribution

In view of the almost universal employment of fully automatic temperature control on annealing and heat-treatment furnaces of every type to-day, it is surprising to recall that twenty-one years ago this feature was practically unknown outside the laboratory.

Temperatures were judged mostly by eye, sometimes aided by an indicating pyrometer, and control was effected by manual adjustment of burners and dampers or by variation of the rate of firing in the case of solid fuels.

As with many other advances in furnace technology, automatic temperature control was pioneered by the electric furnace. In the early days of the latter's development, heat losses had to be held to a minimum if electric heating was to compete on the basis of fuel costs. The resulting necessity for heavy insulation, coupled

Courtesy, Birlec, Ltd.

Fig. 2.—Roller hearth furnace for non-ferrous Tubes.

with the absence of simple means of matching an electric supply to a widely varying power demand (in the manner in which burners can be manually adjusted), made the provision of automatic temperature control on electric furnaces virtually a necessity. Developed first for this purpose, its advantageous features were soon appreciated and it was not long before equivalent systems were evolved for fuel-fired furnaces. Latterly, control equipment has been improved up to a high pitch of accuracy and reliability, while many refinements, such as programme control, have been introduced for special purposes.

Automatic temperature control, while being a desirable step toward greater precision in heat treatment, does not by itself provide the complete answer, unless it is allied with means for providing adequate temperature uniformity in the furnace, or more important, in the work being processed. Advances have been made in this direction also ; examples include the grading of burners or heating elements in relation to the heat demand at various points in the furnace, the provision of underhearth heat when needed, the sub-division of larger furnaces into two or more separately controlled zones, and the use of forced circulation to improve heat transfer and uniformity at low temperatures. These, and other features too numerous to mention, have been developed or improved, and have become standard practice in those types of furnaces to which each is suited.

Atmosphere Control

In some respects of no less significance than temperature control, the provision of properly controlled atmospheres in annealing and heat-treatment furnaces, has received increased attention in recent years.

In direct fuel-fired furnaces, maintenance of the fuel/air ratio at or near the theoretical value for perfect combustion is desirable on the grounds of efficiency, and has been worth pursuing for this end alone. However, it fortunately so happens also that the flue products resulting from complete combustion, substantially free from oxygen or reducing gases, are such as to cause minimum damage by scaling, decarburisation, or other surface effects to steels and some other alloys.

There are, however, only a few metals which can be processed in direct combustion atmospheres with complete freedom from oxidation, notable examples being copper, nickel, and cupro-nickels. For most others, and particularly steels, " bright " heat treatment can be carried out only in a furnace from whose chamber air and flue products are completely excluded, and to which an externally generated reducing atmosphere is fed. Electric heating is particularly adapted to meet this condition, so that the early development of controlled atmosphere processes was closely linked with that of the electric furnace.

More recently, however, introduction of the gas-fired radiant tube element, which can be used in most controlled atmosphere furnaces with equal facility, has largely negatived this one-time advantage of electric heating.

There are available to-day many types of furnaces, batch and continuous, gas-fired and electric, for the carrying out of controlled atmosphere processes, together with appropriate generators for supplying atmosphere gases. The raw material for the latter is often town's gas, or other fuel gas, which by several processes of partial combustion or cracking may be caused to yield a variety of product compositions, reducing, neutral, or carburising

Courtesy, Birlec, Ltd.

Fig. 3.—Shaker hearth hardening and tempering furnaces.

in nature, as may be required. Other sources of conrolled atmospheres, for particular applications, are ammonia, kerosene and charcoal.

Two widely used types of bright annealing furnace are illustrated in Fig. 1, a bell type furnace for strip and wire in coils,—and Fig. 2, a roller hearth furnace for continuous treatment of tubes.

The whole of this large aspect of heat-treatment developments may be said to have arisen during the last twenty-one years.

Mechanisation

During this period, and particularly its latter part there has been in heat treatment, as in many other manufacturing processes, a marked increase in mechanisation. The stimulus for this trend is to be found in rising labour costs, in the difficulty of obtaining labour for arduous or dirty jobs, and in the desire to eliminate as far as possible the human element and the errors which may result from it.

In connection with batch type furnaces, there have been improvements in and wider use of charging machines and various devices for automatic handling of

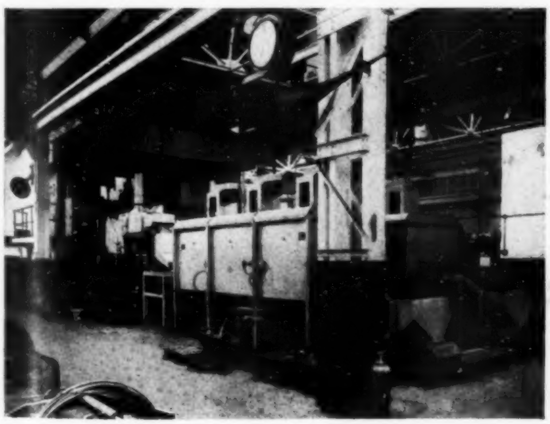
material into and out of quench tanks. But the largest development undoubtedly has been in conveyor systems for continuous furnaces, of which there is now in existence a remarkable variety, and from which a choice can be made, suitable for the handling of almost any type of product. Outstanding examples are the mesh belt and chain belt for forgings and other parts in bulk, the driven roller hearth for strip, rod, and tube, the walking beam for billets, bars and sheets, the rotary hearth, and rotary drum, the pusher tray system, and the reciprocating or "shaker" hearth; the last named, is particularly good for treatment of very small parts and an installation of two such furnaces for bright hardening and tempering of pins and needles is shown in Fig. 3.

It should be emphasised that many of these conveyor systems incorporate mechanisms operating under stress at temperatures up to the highest commonly encountered in heat treatment operations. Their construction would not be possible, had there not been parallel developments in high strength heat-resisting alloys in cast and wrought forms.

A good example of mechanisation in heat treatment is illustrated in Fig. 4, which shows equipment specially designed for continuous hardening, washing and tempering of bearing rollers. There are two production lines and in each the hardening furnace, hopper fed, is of spiral rotary drum conveyor type, from which the components fall into the quench. They are removed by a conveyor of similar type, which transfers them to the continuous washer, thence to the tempering furnace, which is of continuous belt type. No manual operations are involved in this sequence of operations, and all variables are under automatic control.

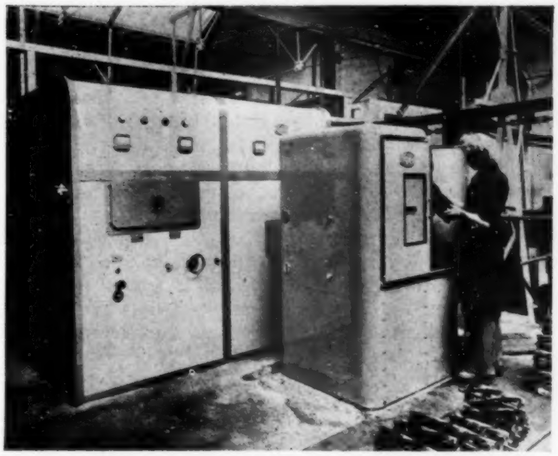
New Heating Methods

Of heating methods which are basically new or whose contribution to heat-treatment progress has largely been felt during the period under review, high-frequency induction heating should receive first mention. The principles involved were known prior to 1929, and had been applied in melting furnaces. But its use for controlled heating in the solid state, and particularly the combination of very high frequency and high-power input, to produce the now well-known surface hardening effect, has arisen almost entirely over the last ten years. An example of induction heating equipment for edge hardening of lawn mower blades is illustrated in Fig. 5.



Courtesy, Birlec Ltd.

Fig. 4.—Automatic heat treatment plant for bearing rollers.



Courtesy, Electric Resistance Furnace Co., Ltd.

Fig. 5.—Induction surface hardening equipment.

There has already been some mention of the important part in new developments which the electric resistor and the gas-fired radiant tube element in their various forms have played, and of the use of forced circulation in low temperature heating operations. Reference should also be made to molten salt baths, which were not unknown before this period, but nevertheless have found extended use for hardening, annealing, hot quenching, solution treatment and tempering. A complete installation for treatment, by this method, of high-speed steel tools, with separate units for pre-heating, hardening, quenching and secondary hardening, is illustrated in Fig. 6.

"Flash heating," i.e., the deliberate use of a high temperature head to produce extremely rapid heating, is another previously known method which has seen interesting new applications in recent years. Examples include electric furnaces for high-speed annealing of those aluminium alloys which show excessive grain growth when annealed by normal methods, and gas or oil-fired equipment for fast heating of billets and bars for forging. The application of high temperature flame heating to surface and local hardening operations might also be said to fall in this category.

Developments in Heat Treatment Processes

The last twenty-one years have seen a great increase in the application of solution treatment and ageing processes. With regard to the aluminium-base alloys, in connection with which these processes originated, there has been notable progress in equipment, particularly for handling of ever-larger pieces—sheets, sections and fabrications—as necessitated by the demands of the aircraft industry. This is one of the fields where both air circulation furnaces and salt baths fill an important place; an installation of the latter, for solution treatment of large sheets is shown in Fig. 7.

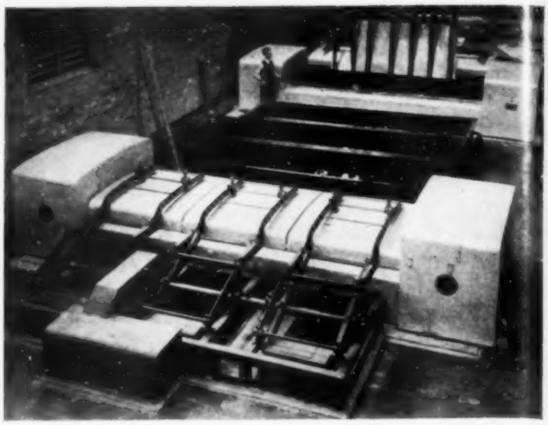
Numerous new age-hardenable alloys have also been developed, based on magnesium, copper, nickel and other parent metals, outstanding examples being the chromium and beryllium bronzes, and the Nimonic series of alloys.

Also noteworthy in the non-ferrous field, has been the increasing application of controlled atmospheres in annealing processes.

A metallurgical field which is not new, but whose industrial application has largely taken place in this same period, is that of powder metallurgy, i.e., the fabrication of components from powder metals both ferrous and non-ferrous, by pressing and sintering. The sintering stage of the process has called for new types of furnace with stringent attention to temperature and atmosphere control. A recently developed electric furnace for sintering at ultra-high temperatures is illustrated in Fig. 8; it is of the molybdenum-wound, hydrogen atmosphere type, capable of a maximum temperature of 1,750° C.

In the ferrous field, outstanding amongst new heat treatment processes, are those based on the isothermal transformation of austenite, such as cycle annealing and austempering, and those which depend on a delayed quench, such as martempering. Time-temperature-transformation curves, or S-curves as they are commonly called, which provide the basic information by which such treatments can be specified, have now been determined for practically all the commonly used carbon and alloy steels. The application of these processes has shown a steady increase; a particularly neat example has recently been reported from the forging industry. Forgings required in the soft condition are transferred straight from the press or hammer, while still at a red heat, to a salt bath maintained at the appropriate sub-critical temperature. On removal after a pre-determined time interval, the forgings have a fully-softened structure, this without employment of any reheating operation.

Of new surface hardening processes for steel components, reference has already been made to induction hardening and flame hardening. Nitriding, first discovered in 1922, has come to fill a small but important place in this field, and its application has been extended to steels other than the originally-developed nitralloy series, notably certain grades of austenitic stainless steels. Case-hardening, i.e., carburising followed by reheating and quenching has, however, retained the widest use, and here there have been useful improvements in methods,



Courtesy, Birlec, Ltd.

Fig. 7.—Salt bath for solution treatment of aluminium alloys sheets.

Courtesy, Electric Resistance Furnace Co., Ltd.

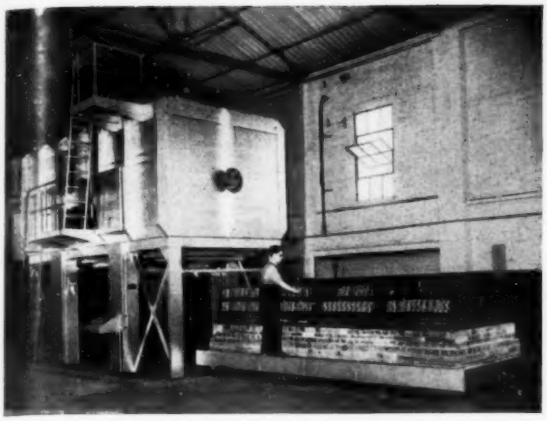
Fig. 8.—High temperature sintering furnaces.

Courtesy, Birlec, Ltd.

Fig. 6.—Salt bath installation for high speed steel hardening.

Courtesy, Birlec, Ltd.

Fig. 9.—Direct quenching from pit type gas carburising furnace.



Courtesy, Birlec, Ltd.

Fig. 10.—Modern annealing furnace for whiteheart malleable castings.

especially in the carburising step. These have been based on the use of gaseous or liquid (molten cyanide) carburising media, in place of packing in solid compound. Improvements also in carburising steels, in the direction of controlled grain size, have in some instances permitted a direct quench from the carburising furnace to replace one or both of the conventional reheating operations. Direct quenching is, of course, much facilitated by the use of gas-carburising, or liquid bath furnaces. A modern pit-type gas carburising furnace, equipped for direct quenching is illustrated in Fig. 9.

Substitution of suitable controlled atmosphere furnaces for the formerly-used packing methods has also been adopted with corresponding advantages in the malleable casting industries. Ingenious methods have been devised for providing the necessary types of atmosphere in these furnaces, decarburising in the case of whiteheart, neutral for blackheart, without the use of external gas generators. A modern whiteheart malleable annealing furnace is illustrated in Fig. 10.

To complete this brief review of new heat-treatment processes, a few words should be included on new treatments for silicon steel sheet. In these, in place of the well-known procedure of hot rolling to gauge and final annealing, the steel instead is cold reduced with intermediate softening, then given a final high temperature anneal with controlled heating and cooling. By these means a grain structure of preferred orientation is produced, which imparts much enhanced electrical properties for certain uses. The intermediate anneals are usually carried out in continuous furnaces and may be combined with a gaseous decarburising treatment. The reduction in carbon content so obtained, to a level of 0·005% or lower, results in a still further improvement in properties.

Magnesium and Magnesium Alloys

Continued from page 328

increased annual consumption. Energy considerations relating to the conversion of MgO to Mg show that the metal can never be as cheap as—say—mild steel ; however, it may be possible to find ways to reduce the present price of electrolytic metal in the production of which the route from MgO to Mg is indirect, and is via the chloride. Work on improved thermal processes continues. The key factor is the price of energy, whether chemical or electrical ; cheap energy gives cheap metal.

Then there is the question of making wrought forms more available by reducing the cost of wrought fabrication. This question is bound up with the availability of special plant properly adapted to the peculiar needs of processing magnesium alloys. German experience showed that, where special plant was available, fabrication costs could be reduced. With the highly workable zirconium-containing alloys now available, considerable cost reductions should be possible with appropriate mills.

Further improvements of the mechanical properties would naturally be useful ; this raises the speculation as to how far it is possible to raise the strength of any given metal by alloying, by heat-treatment, by working and by all three in combination. This problem has attracted the attention of metal physicists, but so far it has proved too difficult for them to provide a reliable guide. If the tensile strength of pure iron is about 16 tons/sq. in., the maximum strength obtained in any ferrous alloy in any state is about 200 tons/sq. in. (accompanied, it is true, by a ductility so low as to make this high strength of no practical value). This represents an "improvement factor" of about 12·5. If one assumed from this that an "improvement factor" of about 10 could be applied in other systems, one could speculate that the "ceiling" strength for magnesium alloys in the strongest condition might be about 70 tons/sq. in. As the maximum strengths so far reached under experimental conditions have been about 28 tons/sq. in., there is a suggestion that there is in fact still plenty of room for improvement. Alloy investigation is actually continuing in many centres in the U.K. and the U.S.

Magnesium alloys naturally experience keen competition from aluminium alloys, and will no doubt continue to do so. Nevertheless in some ways, expansion of the aluminium field is actually a benefit to the position of magnesium. One of these is in the important direction of making the engineering world more familiar with the advantages and peculiarities of light alloys in general. Aluminium and magnesium have many characteristics in common, and any wide acceptance of the one makes acceptance of the other also more easy. Another important factor in this competition between the two light metals lies in the fact that high grade bauxite supplies are far from being unlimited, and less economic aluminium production may be entailed in the future as lower grade materials have to be used. With sea-water magnesia as a source of magnesium, no such limiting factor is likely to apply to that metal. In one important field aluminium and magnesium go hand in hand, that of the aluminium-magnesium alloys containing up to about 10% magnesium. The excellent properties possessed by these alloys is leading to their increasing use in many fields, especially marine engineering.

From the applicational point of view, industrial uses are likely to continue to grow ; the position has, in fact, already been reached when it is no longer legitimate to regard magnesium as exclusively or even mainly an aircraft material.

For continued development, a continuing research outlook is essential. Fortunately there is no sign that those in the industry are tending to relax ; there is on the contrary, every indication that their outstanding energy and leadership will continue unabated.

Progress in the Cold Working of Metals 1929-1950

By W. C. F. Hessenberg, M.A., F.I.M.

The various processes developed for the cold working of metals have been operating for many decades, but during the period of this review a fuller knowledge has been obtained of their effect on the material processed and in consequence great progress has been effected in the plant and equipment employed and in their manipulation, with the result that quality of products and speed of production have greatly improved.

MOST cold wrought ferrous and non-ferrous metals are in the first instance produced by rolling or drawing. These, being continuous processes, lend themselves to the rapid production of large quantities of material and the major portion of this review is concerned with them.

Cold Rolling

By the end of the 1920's the individually driven rolling mill was rapidly superseding the old "train mills." This made possible much greater flexibility in design and from that time onwards something like a revolution in rolling mill practice has taken place. In particular the practice of rolling individual sheets has largely given way to strip rolling which is now carried out on material up to 100 in. wide or more. Perhaps the most notable development in design has been the marked trend towards smaller working rolls. The various theories of the rolling process which were put forward during this period all emphasised that much of the power consumed in rolling and the load imposed on the rolls was due to friction between the rolls and the strip and that both power consumption and roll load rose rapidly as the work rolls became larger in relation to the thickness of the strip. The chief problem of the small work roll was to give it adequate support and to transmit the necessary torque through the very small driving spindles and pinion boxes which they would necessitate. One solution to this problem was the Steckel mill in which two very small undriven work rolls backed up by two heavy support rolls were used and the strip was drawn through the mill by means of a heavy coiler on the exit side. The Sendzimir mill supported the work rolls with several tiers of back-up rolls the last row of which bore directly onto a specially shaped mill housing; power was transmitted to the work rolls via the back-up rolls some of which were driven. These mills, however, represent extreme examples of the trend towards small rolls and their use is at present mainly limited to the rolling of special materials. The general practice in strip rolling to-day is to use a four high mill with work rolls large enough to be driven directly and coilers sufficiently powerful to apply fairly large tensions. (Mention should be made, however, of the new Youngstown 4-high mill in which the back-up rolls are driven).

To-day the multistand continuous cold reduction mills represent the furthest limit of progress in respect of speed and output. These usually consist of five or six four-high stands working in tandem and the last stand finishing at strip speeds which are sometimes claimed to be as high as 5000 ft./min., i.e. about 60 m.p.h. At such rates of production waiting time becomes a predominant item in cost of production and these mills normally embody all the latest developments designed to ensure the longest period of continuous running. Long wearing alloy steel rolls mounted in roller or fluid film bearings are easily withdrawable as a unit to facilitate roll changing; elaborate coiler gear has been developed to handle as rapidly as possible continuous lengths of strip weighing many tons; the acceleration and deceleration periods have been reduced to a matter of a few seconds.

It would be impossible to enter into a discussion of rolling mill drives here, but the high cost and elaborateness of the electrical equipment associated with modern rolling mill drives has led to some interest in hydraulic systems. These have not yet been applied to multistand mills, but there are number of single stand mills in this country and in France in which either hydraulic drive or hydraulic screwdown control are employed. The initial cost of such systems seems at the moment to be not much different from that of electrical equipment, but the saving in both floor space and complexity are very striking.

The introduction of the continuous strip mill together with the tendency to design the mill as a piece of precision engineering has led to great improvements in uniformity of gauge. There is, however, considerable scope for further advances in this field. In particular, the very high strip speeds which are now common have tended to make it more and more difficult for the mill operator to retain continuous control over the thickness of the strip. This will readily be appreciated when it is remembered that in the space of one second 50 ft. or more of strip may have passed through the mill and the operator has little chance of recognizing and correcting for a sudden deviation from the desired gauge. Particularly during the acceleration and deceleration of a high speed mill, the thickness of the strips tends to alter and a considerable quantity of off gauge material is produced for this reason. There is little doubt that the introduction of automatic methods of gauge control is due, and experiments on these lines are being carried out at the present time by the steel industry in this country through their research association.

On the metallurgical side there has been much fruitful investigation of rolling and recrystallisation textures in both ferrous and non-ferrous alloys some of them with important practical results. In the manufacture of cartridge brass, for example, it is important that the finished material should be free from preferred orientation or other directional effects. Formerly this was achieved by limiting the amount of cold reduction between anneals. It is now possible to produce equiaxed structures in this alloy after severe cold reduction by the correct choice of roll pass and annealing schedules, thus removing a serious limitation to the rapid production of

this material on modern high speed strip mills. As a contrast to this, extreme preferred orientation is deliberately sought after in magnet steels of the silicon-iron type where once again the correct sequence of cold reduction and heat treatment is essential.

Wire Drawing

In wire drawing perhaps the most striking single advance has been the introduction of the cemented carbide die for the drawing of wires and rods. Before that, though diamond dies were often used for the finer gauges of wire, larger sizes were invariably drawn through steel dies and the bugbear of the wire drawer in those days was "pulling out" or enlargement of the hole of the die by rapid wear. The very much harder surface of the tungsten carbide die, which has since almost entirely replaced the steel die and to some extent the diamond, has not only made it possible to hold the wire to accurate dimensions for a very much longer time but to allow it to be drawn at much greater speeds.

As so often happens, the solution of the "pulling out" problem has brought others in its train. The cemented carbide die may remain in service so long without serious enlargement of the hole that another form of wear known as "ringing" leads to its eventual rejection. "Ringing" takes the form of a narrow groove running round the inner surface of the die where the incoming wire first strikes it and is thought to be due to the sudden change in stress on the die surface at this point. The material of the die consists of particles of tungsten carbide bonded together with cobalt and it is frequently noticed that at the "ring" the cobalt binder has been removed from the surface and that the carbide particles, being freed, tend to come away; these may cause severe grooving of the die as they pass through it.

There is no doubt that the life of dies could be further improved if the ringing problems could be solved. Efforts are being made to improve the quality of tungsten carbide dies by new methods of sintering and forming the die material; attempts have also been made to make carbide dies by precision casting methods. New materials are also being considered particularly sintered alumina which has already shown considerable promise as an alternative cutting tool material to cemented carbide.

Another approach to this problem is to reduce the severity of the stress gradient at the point where the wire first touches the die. This may be done by applying a tension to the wire before it enters the die, a method which has become generally known in recent years as "back pull" or "reactive" wire drawing. At the beginning of the period under review an investigation of the mechanics of back pull drawing was being undertaken at Sheffield University the results of which gave rise to widespread interest in this country, the U.S. and Germany. Patents were filed and exaggerated claims were made. It is only recently, however, that a more sober judgment has been possible, and at least one company in this country has produced a number of "straight line, non-slip" multihole machines for drawing steel wire which have given promising results both in this country and the U.S.A. These machines work on the principle of allowing a degree of inter-capstan tension and are therefore "back pull" machines. One of these was made available for an investigation by the British Iron & Steel Research Association as the result of which it was concluded that the application of back pull itself appeared to lead to no striking advantages and was without effect on the properties of the wire, but had the particular merit of making possible the straight line passage of the wire from block to block which results in a simple design of machine and a rapid passage of the wire through it which is of considerable metallurgical importance when drawing material whose properties are affected by heat.

High carbon steel wire such as is used in wire ropes is particularly sensitive to drawing temperature; strain ageing takes place with increasing rapidity as the temperature rises and the properties of the finished wire are impaired. Formerly such wires were drawn slowly and even "rested" between one pass and the next while every attempt was made to keep it cool at all stages. With the new straight line type of multihole machines it has been found possible to draw heavy gauge high carbon wire at speeds up to 1500 f.p.m. without any ill effects. The reasons for this is that strain ageing, like many metallurgical changes, is a function of both temperature and time; and whereas the old methods aimed at keeping the temperature down, the new method so shortens the time during which the wire is in the machine that it arrives on the finishing block where it rapidly cools to room temperature before strain ageing has time to take place to any appreciable degree. This represents a very great advance in rate of production and it is likely that we shall see further developments in straight line slipless multihole drawing machines for heavy gauge wires.

Attempts have been made from time to time to draw wire without the use of dies, for example, by passing it from one drum onto another rotating at a higher speed sometimes with devices for localising the deformation at some point between them. Up to the present it seems that no method of continuous "dieless" drawing has yet been used in production. There are difficulties to be overcome but the possibility exists that some form of "dieless" drawing may become more widely used at some future period. If so, many of the problems associated with the use of dies will disappear.

Deep Drawing and Pressing

Cold rolled and annealed sheet metal forms the basis material of a large group of cold working processes of the non-continuous or "one-shot" type. These are mostly carried out with press tools and are often collectively referred to as "deep drawing and pressing." Progress in this field has been mainly a matter of steady development of technique rather than the result of any revolutionary changes, but a comparison of the motor-car body of to-day with that of 1929 will show at once how great that progress has been. The great majority of motor-car body pressings are made from steel sheets in the production of which there have also been very substantial advances notable in the production of wide strip and the production of special quality deep drawing steels. As is well known, mild steel tends to age after temper rolling with the development of a sharp yield point which gives rise to special difficulties in deep drawing. A good deal of research has been carried out with a view to overcoming this and a number of "non-ageing" steels containing additions of Al, Va or Ti have been developed. Whether such special steels will become generally adopted for deep drawing remains to be seen. An interesting recent development has been

the production of anisotropic deep drawing steel for making long thin pressings such as motor-car bumpers where the deformation is more severe in one direction than another.

Light alloy pressings are used extensively by the aircraft industry particularly strong alloys of the Dural type. These too are prone to age hardening at room temperature and formerly had to be pressed immediately after solution heat treatment. The development of refrigeration storage for deep drawing sheets has enabled this difficulty to be alleviated. In addition to press working, extensive use was made in the last war of "stretch-forming" in which the light alloy sheet is firmly gripped at its edges and a shaped tool forced against it causing it to assume the desired shape. The process lends itself to the production of small quantities of pressings of different shapes since the cost of the tools and equipment is low in comparison with deep drawing.

The high cost of deep drawing tools has also led to a number of developments in tool design and materials. Zinc alloy dies are used for shallower types of pressing while cold rolled zinc or light alloy dies are employed in some blanking operations. Rubber has also been used as the "die" for a soft metal tool, it being unshaped but taking up the general form of the punch with the sheet formed to shape between them when pressure is applied; this process can also be used for blanking. Another recent development is the use of a special lacquer with which the blank is coated before pressing. This is easily removed afterwards and in the meantime the surface of the metal has been protected from surface marking by the press tools.

Impact Extrusion

Within the period under review, the impact extrusion process has become very widely used for making collapsible tubes, battery cans, radio parts, aircraft radiator tubes and many other parts—which are generally in the form of cylindrical or rectangular tubes. If the tube is long and thin as in the case of copper radiator tubes the Hooker process is used: for most other applications, the tube is extruded back round the punch. Most of the ductile non-ferrous metals can be formed by this process and experiments are now being made with steel; in principle there is no difficulty here, but the question of tool wear is the limiting factor at present. A particularly interesting example of impact extrusion was the production, during the war, of tin coated lead collapsible tubes for toothpaste. The blank was cut from tin clad lead strip, the two metals adhering throughout the extrusion to give a continuous tin coating to the lead in the finished article.

Twenty-One Years of Powder Metallurgy

By H. W. Greenwood

Powder Metallurgy, Ltd.

In the period under review powder metallurgy has literally grown from infancy to the position of offering the unique solution to quite a number of major metallurgical and engineering problems. Progress in this country is providing a considerable contribution to vital knowledge on the subject of great scientific importance and value.

THE Coming of Age of an individual, equally of a periodical, is an occasion. It is inevitable that advantage should be taken to survey the past and, so far as possible, look into the future. Whether we desire it or not such surveys are of great importance in these days when the tempo of both life and industry has accelerated so rapidly. Metallurgy in the years since the founding of METALLURGIA has advanced phenomenally. Powder metallurgy has literally grown from infancy to the position of offering the unique solution to quite a number of major metallurgical and engineering problems.

It may be of interest to recall the broad lines of the position and the knowledge of 1929. Without doubt powder metallurgy at that time was on the threshold of a period of remarkable expansion. Much of the progress prior to that time had followed much earlier work, especially in the production of drawn and ductile metals commencing with powder. These included the production of osmium, tantalum, tungsten and molybdenum in wire and sheet form starting from powders. Carbides had been introduced in Germany and in the United States. Compound metals for use in the electrical industries were in production, and the early master patents covering the modern type of porous, self-lubricating bearings had been taken out and the production described by Gilson[1] in 1921. Powder iron cores had been produced for use in electric circuits by Polydoroff about 1927[2]. By 1929 there had appeared in metallurgical literature quite a number of papers dealing with various theoretical and practical aspects of powder metallurgy, and fairly clearly indicating the general direction in which the comparatively new and young branch of metallurgy would develop. There was, however, no book gathering up the various threads and weaving a recognisable garment from them. That did not appear until 1930 when Franz Skaupy published a little book of some seventy pages entitled Metallkeramik. To this he added an appendix of a further ten pages in 1935. It was left for W. D. Jones to produce the first treatise on the subject with his "Principles of Powder Metallurgy" published in 1937. In the previous year there had been an important contribution made in Russia by M. J. Balshin on the "Theory of Metallo-Ceramic Processes."[3]

While on the subject of literature it may be useful to mention the actual books published since Dr. Jones' work appeared. The next important one was the volume entitled "Powder Metallurgy" edited by John Wulff and containing the papers presented at the 1940 and 1941 Conferences on Powder Metallurgy held at the Massachusetts Institute of Technology and published by the American Society for Metals in 1942. Next came an

1 Gilson, E. G., *General Electrical Review*, 1921, **24**, 949.

2 Crossley, A. J., *App. Physics*, 1943, **14**, 9, 451.

3 Balshin M., *J. Vestnik Metallopromishlennosti*, I, 1936, 16 (17) 87–120; II. 1936, 16 (18), 82–90, and III, 1936, 16 (18), 91–99.

important German work in 1943, " Pulvermetallurgie und Sinterwerkstoffe " by Kieffer and Hotop. America provided " Powder Metallurgy " by Dr. Paul Schwarzkopf in 1947, and the next year saw another valuable work from Germany, " Sintereisen und Sinterstahl " by Doctors Kieffer and Hotop and last year saw the first volume of Dr. Goetzel's " Treatise on Powder Metallurgy " from the United States.

Of the growth of separate communications and papers it is perhaps sufficient to say that so numerous have they grown that it has been found convenient to publish an abstract Journal in this country " The Metal Powder Report " which appears monthly and carries some 16 pages of matter. This has its opposite number in the United States in the monthly " Metal Powder Bulletin." In his valuable review of the literature of the Powder Metallurgy of Iron, G. H. S. Price[4] cites some 71 papers and of these all but seven have been published since 1929.

In any review of powder metallurgy the first item to be discussed is usually the preparation of the metal powders themselves. There have been many improvements in, as well as additions to, the methods of preparation, but perhaps the outstanding fact has been the increasing use of atomising as a method of production, the uneconomic nature of electrolytic methods of producing powder except when current costs were very low, and the parallel failure, up to the present time, to produce an iron powder which could adequately compete as to price and quality with Swedish sponge iron powder. We are still short of adequate supplies of various stainless steel powders, although some ingenious methods of preparation, including intergranular corrosion, have been developed in America and have produced powders having some desirable characteristics for pressing. It is still true that manufacturers prefer the devil they know to the devil they do not know, and though this may be dubbed conservatism, it is a safe procedure. Thus, a number of powder metallurgical techniques follow well established ways and use methods that, young though powder metallurgy may be, are now of quite respectable age.

The older products such as porous bearings and metal bodies having controlled porosity have mainly advanced in greater dimensional accuracy and in the replacing of the more expensive bronze by the cheaper iron. New developments have been in the production of steel backed copper-lead and various other lined bearings of which a sound review was provided by W. H. Tait at the 1947 Symposium held in London[5]. The development of materials having carefully controlled porosity for use as filters has already provided valuable aids in industry and has had application as de-icing equipment for aircraft, a still more recent line of investigation covers the production of porous components such as turbine rotor or stator blades having a capillary porosity such as to permit of sweat cooling.

Laminated products particularly carbon-copper current collector brushes were known well before 1929, but the requirements of the electrical industry have never been static and year by year new possibilities have been suggested and new combinations tried out. The refractory metals early claimed attention, and the idea of combining high refractory qualities with good electrical and thermal conductivity was soon developed and to-day bi-metals consisting of molybdenum or tungsten with copper or silver are a commonplace in switchgear and combinations of other metals are in use for various special duties.

This brings us to a consideration of developments that have taken place in producing parts. The earlier parts produced by powder metallurgy were porous and, almost without exception, had poor physical qualities. Generally they were small in dimension and such as could be produced in very large quantities by multiple die presses. As such their low physicals were not a very serious handicap. It was clearly realised that their porosity was the determining factor and so work was done to reduce or eliminate this disadvantage. Two lines of investigation were followed, the earlier was the attempt to get denser parts and better physical qualities by hot pressing. In this way it was hoped to compensate for the higher cost of hot pressing by the less pressure required, the decreased die wear and the lower cost, or possibly even the elimination of sintering. A certain measure of success attended the process, but it had obvious disadvantages and the next step was in an entirely different direction, namely infiltration. The idea of sintering in the presence of a liquid phase was familiar through the methods used in the production of cemented carbides or hard metal for tools, where cobalt or nickel were used to cement the extremely hard and refractory particles of carbide into a solid mass. There was also the experience gained in the production of heavy alloy,[6] where the addition of 5% nickel and 2% copper to fine tungsten powder resulted in parts of nearly theoretical density and excellent physical properties.

The fact that a porous metal mass could have its pores filled by capillarity if a liquid of the right wetting power and viscosity were used was common knowledge from the practice of producing oil impregnated bearings and so the process of impregnation or infiltrating porous sintered bodies with a metal of lower melting point was initiated, found to be a successful method of obtaining enhanced physical properties and now bids fair to open up many new avenues of useful service to powder metallurgy. The commonest example is that of a sintered iron sponge being infiltrated with copper and some notable figures have been published of the results obtained by this technique[7]: it has extremely wide possibilities and some particularly interesting figures are available in which sintered stainless steel has been infiltrated with copper[8] and has helped in the production of parts for turbines where the temperatures involved are not too high.

Actual accomplishment to date have shown that infiltration is of great promise and that solutions have been provided for a number of problems that have troubled the maker of small iron parts. It has simplified the brazing of sintered parts as well as the plating, removed the reproach of poor physical properties and facilitated the building up of complex sintered assemblies from smaller and simpler units. A particularly hopeful avenue is the infiltration of steels with alloys and metals susceptible to precipitation hardening. Mention of steels is a reminder that valuable progress has been made in the production of a wide range of alloy steels using a powder metallurgical technique in which hot pressing may be an integral part.

Price, G. H. S., A Review of the Literature on the Powder Metallurgy of Iron. *Metal Treatment*, Winter, 1945–46.

Tait W. H., Powder-Metallurgy Bearing Materials. Iron and Steel Inst. Special Report, No. 38, 1947, pp., 157–161.

6 Price, G. H. S., Smithells, C. J., Williams, S. V., *J. Inst. Metals*, 1938, 62, 239.

7 Schwarzkopf, P., *Metal Progress*, 1950, January, p. 64.

8 Stern G., *Materials and Methods*, 1950, June, 52–54.

In addition to copper other materials can be used in infiltrating and an ingenious use of alloys of copper with chromium, silicon and other elements has been made. Chromium, silicon and certain other elements inhibit the solution of iron by copper. It was found out quite early in experiments in cementing by infiltration that as copper dissolved iron further solubility of iron was prevented and the infiltration slowed down and finally stopped. Another benefit of using alloys of copper with these elements was the prevention of freezing of the iron-copper alloy which also brought the cementing operation to a close.

Another form of infiltration has been the use of coated metal powders, particularly iron powders coated with copper. This technique has been used with cast iron powder to produce pressings from the cheap brittle cast iron powder which would have good green strength and good physical properties after sintering. Various methods have been used to apply the copper coating of which the latest, and one that may offer very wide possibilities is a thermochemical process of the thermit type which has only recently been described in the United States[9]. Coated powders whether produced in this or in more conventional ways have certain excellent properties; they press easily and on sintering provide excellent physical properties, tensiles of from 45 to 50 tons per square inch being attainable.

Possibly the most important and outstanding progress in any powder metallurgical technique has been that in which the cemented carbides have played so great a part. Twenty-one years ago they were about three years old and while their amazing cutting powers were already recognised they had not arrived at any widespread use in this country. To-day, their service comprises cutting and milling of almost every type of material known in industry, but they have widespread application in the withstanding of shock and abrasion. Their use, in addition to cutting, includes the provision of moulds and dies where high temperatures as well as powerful abrading materials have to be withstood. A recent achievement has been the production of percussion drill heads for rock-drilling.

A field closely allied to the cemented carbides is that comprising those combinations of metals and ceramic materials such as the refractory oxides and silicates as well as the lesser known borides, carbides, nitrides and similar compounds. To these the general name of cermets or ceramals has been given. Their great interest at the moment lies in the possibilities they offer in the production of gas turbine blades and associated products required to withstand stress at high temperatures and for long periods. A useful summary of the subject and results on turbine blades of 80/20 titanium carbide/cobalt were published last year [10].

Powder metallurgy has made valuable contributions toward the economical production of magnets, particularly permanent magnets, which play so large a role to-day as components of scientific instruments, especially in communications and transport. Earphones, small synchronous motors, timing devices, moving magnet instruments, and a host of recording mechanisms are but some of the services they render. This is a field wherein the passage of time has seen a wholesome change of opinion as to the relative merits of casting versus pressing and sintering in the production of permanent magnets. From widespread and largely unsupported claims of superiority we have progressed to an understanding that the production of high duty permanent magnets is not an easy procedure by any particular process, and that where powder metallurgy does have distinct advantages is in producing small magnets of irregular shapes, in the control of the purity and freedom from, or freeing from traces of oxide, of the materials used, and in the more accurate control of composition that the powder method permits.

A notable development of the past twenty years has been the utilisation of iron powders for cores in electrical circuits and the gradual development through hydrogen reduced iron powders, the introduction of carbonyl iron powder, particularly for tuning devices operating at high frequencies and the later use of the iron-nickel permalloy type of powders with or without the presence of molybdenum[11].

Without doubt the outstanding feature of progress in powder metallurgy in the last few years has been the transition from a series of empirical processes to an appeal to, and a demand for, a much closer study of the fundamental knowledge governing the properties of matter in general, and of metals in particle form in particular. A sign of this has been the appearance of specialised treatises on such subjects as the theoretical principles governing matter in a fine state of division such as Dalavalle's monograph on "Micromeritics"[12], and the outstanding monograph on Physics by Bowden and Tabor on the "Friction and Lubrication of Solids"[13] as well as volume I of Dr. Claus Goetzel's "Treatise on Powder Metallurgy"[14]. These publications and the tremendous volume of literature, already referred to, indicate in no uncertain manner that there are to-day few activities in peace or in war that do not demand the aid and co-operation of the powder metallurgist and his products. Statistics of production in this country are almost impossible to obtain, but an idea of the growth of production of pressed and sintered parts in the United States can be gathered from reports of the Metal Powder Association of America which has been collecting and keeping records for some little time. It is reported that the amount of iron powder used in powder metallurgy in the U.S.A. in 1949 was two and a half times as much as in 1946; and further that the number of bearings and parts produced in 1949 by members of the Association was well over a billion, that the number of companies engaged in commercial production of metal powder parts was about 100 and the value of their products in 1949 approximately $125,000,000. In this country we cannot supply such figures, we can record steady development, especially toward the solution of some of the tougher problems facing us. We can also claim the solution of many major metallurgical and engineering problems have been solved by powder metallurgy methods and that our progress is second to none in the world in scientific importance and value: no other country is making a larger contribution to the vital knowledge upon which all future achievement will depend.

9 Drapeau, J. E., Junr., Proc. 6th Ann. Meeting, Metal Powder Association of America. Published M.P.A., New York.

10 *Trans. A.S.M.E.*, 1949, **71**, pp. 621-629.

11 Liegg, V. E., and Given, F. J., Bell Telephone System, Monograph B., 123 (1940).

12 Dallavalle, J. M., "Micrometrics," Pitman Publishing Corporation, New York. (1943).

13 Bowden, F. P., and Tabor, D., "The Friction and Lubrication of Solids." The Clarendon Press, Oxford, 1950.

14 Goetzel, C. G., "Treatise on Powder Metallurgy," Vol. 1. Interscience Publishers, New York. London, 1949.

Progress in Metal Finishing Since 1929

By S. Wernick, Ph.D., M.Sc., F.R.I.C., F.I.M.

It has taken the best part of the last two decades to remove the natural suspicion which prevailed between the scientists and chemists on the one hand, and platers and metal finishers on the other, and this in itself represents an important advance in electrodeposition: in addition, however, this review indicates that big advances have occurred in the metal finishing industry.

When I was invited by the Editor of this Journal to contribute the article on metal finishing for this special issue, my thoughts immediately conjured up a scene in the office of an Editor of another well-known British metallurgical journal 21 years ago. The latter, who has since left the earthly scene, was, in his day, one of the most distinguished men in the field of metallurgical journalism; he belonged to the old school and was none the worse for that. He was not often wrong in his opinions—technical or otherwise—but when he propounded the view that the new metallurgical journal which had appeared on the horizon, Metallurgia, would be fortunate if it survived a few issues, he showed himself, as events have undoubtedly turned out, to be very sadly lacking in prophetic powers.

Nineteen hundred and twenty-nine! Those were exciting days in the metal finishing world. Looking back it would seem that the dawn of a new era in this fascinating and mixed field of technology was about to open up. Chromium plating, it is true, had already been established, but it was little realised then how widespread would be the field which it would eventually embrace. The general attitude of the metal finishing fraternity towards this remarkable finish was still one of caution not unmixed with awe. It was not many years previously that an unassuming student by the name of G. J. Sargent had read a paper in the United States before an august scientific body enunciating the principles of the electrodeposition of chromium—a paper which hardly caused a ripple of excitement at the meeting, and certainly received little or no attention from the technical press of the time. Nevertheless, it may well be said that the immense ramifications of this perhaps most important of metal finishes are based on the facts which were enunciated by young Sargent in 1920*.

In 1929, the Electrodepositors' Technical Society was an infant body, scarcely five years' old, and the executive officers at that time realised that one of the most difficult problems which had to be faced in order that the scientific truth might be disseminated and accepted by men in the metal finishing industry, was to overcome the very natural suspicion which prevailed between the scientists and chemists on the one hand, and platers and metal finishers on the other.

It has taken the best part of a couple of decades to effect this desirable state of affairs, and perhaps it is not too much to suggest that this in itself represents the most important advance in electrodeposition! The art of metal finishing, which was so much a feature of this field of industrial endeavour in the early part of the century, has given way to methods based on the sure foundation of science. Nevertheless, there are still many processes in operation which owe much to the individual art and attention based on years of individual experience of the metal finisher. Such finishes and methods for their production while they remain to be admired, often do not, unfortunately, fit into the economic pattern which has become such an important part of our everyday outlook.

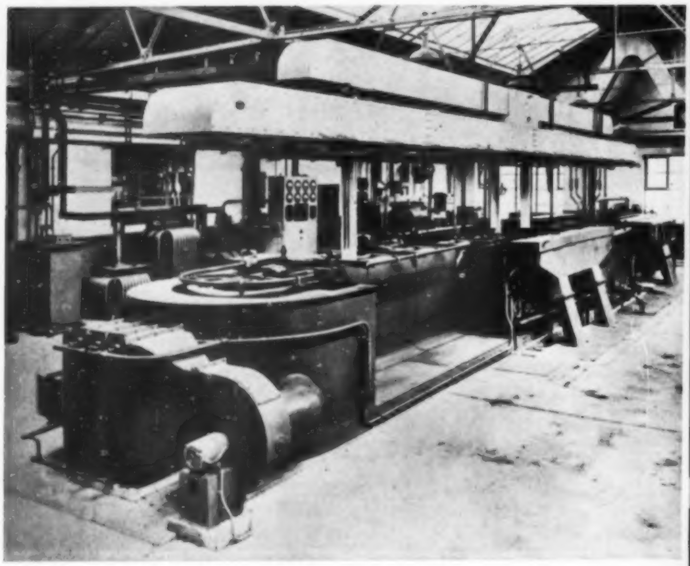
Bright Nickel and Chromium Plating

In 1929, nickel plating was based very largely on the use of the Watts type solution. This was a development of the old nickel electrolyte which was based on the double nickel salt. By heating the solution, filtering it, and keeping it in circulation (usually by air agitation), thus ensuring that the nickel anode electrolyte interface was continually re-charged with nickel ions, it had been found possible to increase the rate of deposition very appreciably. The quality of the deposits was correspondingly improved not only by reducing the tendency towards porosity, since thicker deposits could now be produced in less time than previously, but also the physical properties were enhanced and the deposits were softer, more ductile and freer from internal stress.

While all this was to the good, one of the big difficulties had yet to be overcome. Nickel plating which was applied for decorative purposes was usually deposited on a basis metal originally polished to a high lustre. When the article was removed from the bath, the initial polish had gone and it was then necessary to repolish the surface. As a result of this, a considerable amount of nickel deposit was removed, and, depending on the buffability of the deposit (which is not necessarily allied to softness, incidentally), a fairly important percentage of the deposited nickel would find its way into the flue of the polishing machine. More important than this, from the point of view of the protective quality of the nickel, was the fact that most usually the nickel would be removed from those parts of the contours which had received the least amount of deposit; hence, the sequence of operations, buffing of basis nickel—nickel plate—nickel buff, resulted in a highly polished nickel surface it is true, but one which was far from satisfactory from the protective point of view.

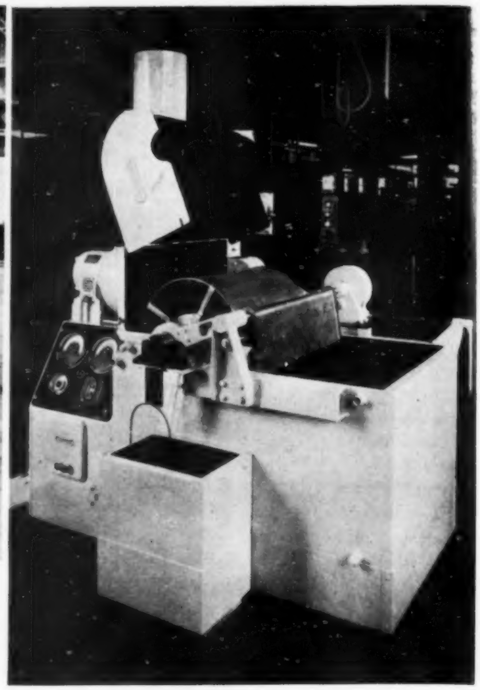
Electrochemists, therefore, looked about them to see whether it would not be possible to develop a nickel electrolyte which would simultaneously plate fast and also introduce such brightness into the deposit that it would not need further buffing when it left the nickel bath. Many were the initial failures to achieve the objective, among them, more than one lamentable commercial fiasco arising when some supply house announced prematurely that they had achieved the ideal and were prepared to offer the solution to all who would use it in the industry. Many a so-called bright nickel solution, alas, found its way into the drains primarily because the factors surrounding the problem had not been fully studied. It was one thing to produce

* Sargent, G. J., *Trans. Amer. Electrochem. Soc.*, 1920, **37**, 479–96.



Courtesy of Messrs. Electro-chemical Engineering Co., Ltd.

Fig. 1.—Automatic plant for nickel chrome plating brass parts by Efco-Udylite process.



Courtesy of Messrs. W. Canning & Co., Ltd.

Fig. 2.—Continuous barrel chrome plating plant

a solution which plated bright initially; it was another to maintain this brightness in face of continuous contamination which all electrolytes, whether nickel or otherwise, must necessarily suffer.

The problem was being intensively studied not only in this country but also the United States, and it was solved simultaneously by the development of a bright nickel solution based on the deposition of an alloy containing up to 15/18% of cobalt. In America, this process was developed by Weisberg; in this country, a similar process was developed by Hinrichsen. The cobalt bright plating solution has, however, been used to a much greater extent here than in America, where in addition to the cobalt type solution, other bright nickels were developed based on organic addition agents of the sulphonate type initially, and later embracing many other classes of organic compounds.

It may be said that so far as this country is concerned, the cobalt bright nickel has done yeoman service. It has had a vogue now of a dozen years or more, and it is only in the last year or two that there has been a tendency to abandon the process in favour of organic type bright nickels, and then only reluctantly, because of the high price of cobalt and the necessity to economise as far as possible in production costs.

Electroplating Plants

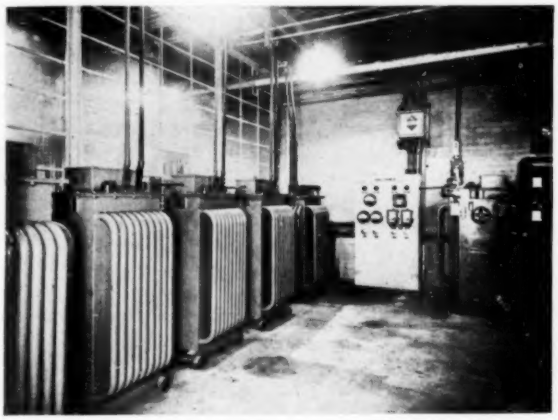
The electroplating plant capacity of Great Britain has seen a very considerable increase in recent years. The war years, in particular, far from resulting in an eclipse in metal finishing, as was first thought probable, proved to be a period when electroplating and metal finishing plant was called for in great quantity. All that happened during the war was that the type and class of finishes were changed; thus, while chromium plating faded out, other finishes, such as the anodic oxidation of aluminium and its alloys, steel blacking processes, protective chromating treatments, zinc and cadmium plating, etc., more than made up the leeway. By the end of the war, outputs of these finishes were on a considerable scale and plant had multiplied correspondingly. With the advent of peace, when the decorative finishes came once again into their own, the bulk of this plant was adapted to produce the new finishes, which came once again into demand.

One of the most significant changes resulting from the war period was the demand for automatic plating plant as opposed to the continuation of the use of manual methods. Where before the war the sight of an automatic plant in a British works was rare, to-day they may be seen all over the country, and indeed, are employed wherever the products which have to be finished are mass-produced in sufficient quantity to warrant the initial outlay—which is, of course, much greater than that required for manually operated plant. Where the output of the products is intermediate in required quantity, the use of semi-automatic plants has been found to answer the need.

There are many advantages connected with the use of automatic plating plants and they are not merely employed to reduce the manual labour necessary in the operation of still type plating tanks. An automatic plating plant ensures that a sequence of operations is carried out in an identical manner with respect to timing in each of the process tanks, rinses, etc., and, therefore, in effect standardises the finish. It can only do this if, allied to the use of the "automatic," auxiliary control equipment is employed which will standardise the variables, be they chemical, electrical or otherwise. It should, however, be emphasised that while one of the most important functions of an automatic plant is to produce a uniform finish, this does not automatically infer that the standard is necessarily the optimum. It

is not perhaps sufficiently realised that an automatic plant can as consistently produce defective plating as it can plating of quality—depending entirely on the control of the factors which enter into the production of satisfactory plating.

The demand for good quality plating has become a very insistent one, and indeed it is not too much to say that it is a matter of national policy to ensure that high quality finishes are applied to the metal surfaces of many of the components and goods which are eventually exported. A satisfactory surface is necessary to attract the buyer and to produce a durable finish in service. The export market to-day for many of our important goods include many overseas countries where the atmospheric conditions are such that rapid corrosion will occur unless adequate protection is achieved. There is no doubt that standards of plated finishes have, as a result of the demand by manufacturers, consistently improved, but there are still some black spots in the industry here and there. A British Standards Institution Committee which is now in session has the predominant aim of producing standard specifications which will ensure a minimum standard of satisfactory finish.



Courtesy of Messrs Westinghouse Brake & Signal Co., Ltd., and Messrs. W. & T. Avery, Ltd.

Fig. 3.—Rectifier equipment and control gear for heavy nickel plating.

Control Equipment

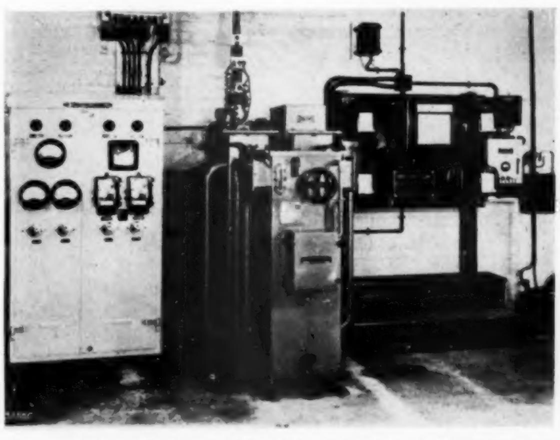
Probably one of the most important advances in the last two decades in plating practice centres round the realisation that plating solutions become rapidly contaminated, and so freedom from contamination, both organic and inorganic, improves quality plating. This has become even more apparent with the advent of bright plating processes, which are far more sensitive to impurities and contaminants than the old type electrolytes. Accordingly, methods of decontaminating electrolytes have been evolved, filtration equipment of special design has been brought up to eliminate solid impurities, and in most plants such equipment is used continuously. Other methods involve the "plating out" technique, which is dependent on the principle that inorganic impurities may be deposited on auxiliary cathodes at very low current densities.

On the electrical side, the industry has been almost transformed by the introduction of rectifier equipment to provide D.C. power, and this type of plant has been found to be so reliable, carrying many technical advantages, that motor generators have been replaced to a considerable extent in consequence. It is particularly gratifying to record that this development is one in which Great Britain has led the world. The quality of British rectifiers has not been seriously threatened by those produced elsewhere, and having regard to the much larger output of plating produced in the United States, it is remarkable that the progress made in the latter country in this field has not been nearly so notable. The latest developments in respect of the use of rectifiers for power purposes in the plating industry is along the lines of controlling the current density in plating solutions so that when a varied load enters the plating bath it may be possible to apply a reasonably uniform current density to components irrespective of shape, size, etc. The estimation of current density on articles of complex shape, is an extremely difficult matter to determine, and the development of apparatus of the type just mentioned will prove to be a real boon to the plating industry, which has now to satisfy very rigid specifications.

Paints

In the paint field, there have been numerous advances, not only in respect of the types of constituent employed in the production of paint but also in methods of achieving rapid drying. The trend away from cellulose paints into the synthetic class has been a steady one, and has made most marked progress in America. Synthetic paints are being increasingly used, in particular, in the motor car industry, which represents one of the most important outlets for paint. Cellulose paints have by no means been completely ousted here, but the synthetics have already shown considerable advantages in respect of appearance, durability and rapidity of application.

One of the most interesting developments in the production of highly protective paint finishes in the automobile industry is the "Roto-Dip" plant, which is being installed in British motor car factories for treating car bodies in the sub-assembled stage. The body is rotated on a spit and taken through a series of tanks which ensures correct chemical pre-treatment



Courtesy of Messrs Westinghouse Brake & Signal Co., Ltd., and Messrs. W. & T. Avery, Ltd.

Fig. 4.—Close-up of control unit for maintaining specified amperage.

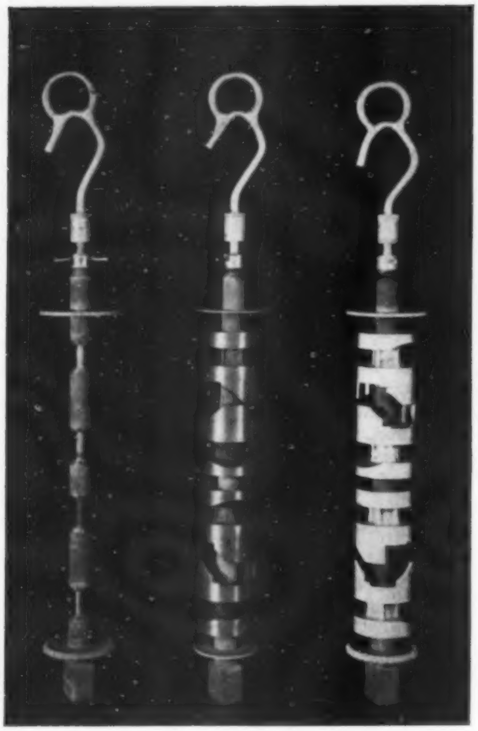
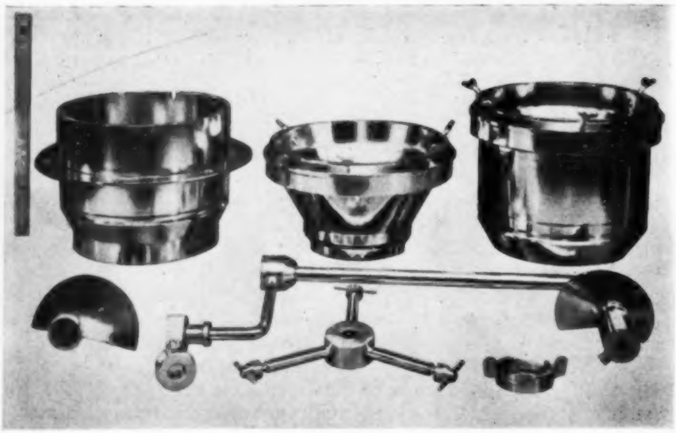


Fig. 5.—Heavy nickel plating on cast-iron pistons. Left to right: (a) Jig for racking pistons; (b) Cast-iron pistons before deposition; (c) Cast iron pistons with heavy nickel deposit (note comparative uniformity of nickel)



Courtesy of Messrs. Modern Electrolytic Patents & Processes, Ltd.

Fig. 6.—Electro-polished and chemically polished articles.

before priming. As a result, not only the outside but inside parts of the car body are fully protected and superior corrosion resistance in service may be expected in consequence.

Chromating Treatments

The use of chromic acid and chromates to increase the protection of metal surfaces has been widely introduced in the last decade or so. It has been successfully used to impart corrosion resistance to zinc surfaces, both in the form of zinc plating and also directly upon zinc base die-castings. Zinc, while an excellent corrosion preventive for steel, will itself corrode to form unsightly corrosion products and chromate protection largely inhibits this occurrence.

Chromate treatment has also been applied very successfully to tin surfaces—particularly tin plating, the life of which has been considerably increased as a result of such treatment. Furthermore, chromating has been shown to have a beneficial effect when applied to phosphate coatings. It appears to seal such parts of the ferrous surface as have not been completely phosphated, and corrosion tests appear to show that the protection of the phosphate coating is thereby enhanced.

Tin Plating

During the second world war, when tin supplies were very largely in enemy hands, an acute shortage of tin made it necessary to consider other means of producing hot tinned steel, so largely used, for example, in food canning. The tin applied in the old way could not be reduced in thickness below a certain minimum. By the use of electrolytic methods, it was possible to reduce the tin coatings very considerably and the desired economies were thereby effected. The situation called for the production of electro-tinning plants of huge capacity, and many such automatic plants were built during the war in America. Similar developments have followed in this country and the method, which produces a tin coating of adequate quality, is now in wide use.

Deposited tin has also been employed in the production of alloy finishes. One of the best known, that of Speculum, consists of the binary alloy, tin-copper. This finish has found limited application, but there is no gainsaying the attraction of the finish, which is used in the production of certain classes of articles. Deposits of the tin-zinc alloy have also been developed and these have been found to have highly corrosion resistant properties. The latest work (most of which has been sponsored in this country by the Tin Research Institute) is directed to the deposition of the tin-lead alloy.

Protective Plating—Zinc and Cadmium

The tonnage of zinc and cadmium employed in the form of anodes for plating has risen continuously in the last 20 years. In certain industries, for example, the electrical trades, these finishes have found extremely

Courtesy of Messrs. Modern Electrolytic Patents & Processes, Ltd., and Messrs. Rolls Royce, Ltd.

Fig. 7.—Electro-polishing of Nimonic turbine blades.

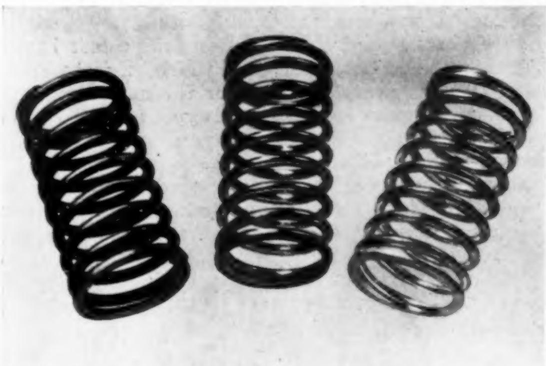
wide application. Their value as protectives has been overwhelmingly demonstrated, since much of the electrical equipment employing these finishes is exported and has to stand up to very onerous climatic and service conditions abroad.

The difference in price between the two metals is so marked that it is sometimes surprising to find cadmium plating employed where the much cheaper zinc plating would appear to be entirely adequate. Cadmium plating has, however, become extremely popular due no doubt largely to its capacity for resisting staining and the superior finish which it imparts.

Bright zinc plating processes have been introduced of late to compete with cadmium, and since such processes are still more economic than cadmium, they are gaining substantial headway.

Heavy Nickel Plating

Heavy nickel plating, a development which was initiated during the first world war, has made considerable headway, and commencing as a process arising from necessitous conditions, is now widely used in the salvaging of expensive engineering components. Originally, the process was designed to salvage armament components; to-day, it is employed in the engineering, automobile, ship-building and other heavy industries, wherever worn or undersized components required to be built up in metal. It does, indeed, represent the oft-dreamt-of "putting-on" tool, so useful to engineers. In some cases, the heavy nickel deposit, which has sterling mechanical properties and the adhesion of which to the basis metal (usually steel) is of a phenomonally high order, is applied deliberately as a final coating because of the excellent service which results from its use.

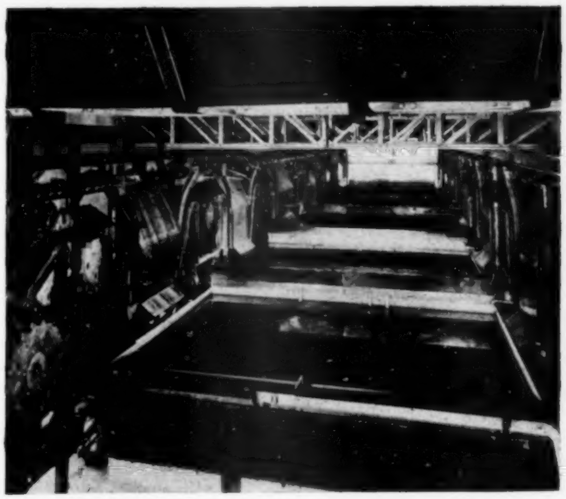


Courtesy of Messrs. Modern Electrolytic Patents & Processes, Ltd.

Fig. 8.—Super-finishing of steel springs in three stages: (a) before super-finishing; (b) after electro-polishing; (c) after cadmium plating.

Hard Chromium

Hard chromium deposits, which succeeded heavy nickel as a building-up material, confer the additional advantage of extreme toughness and abrasion resistance and there are not lacking applications for this process in consequence. The process is necessarily a more expensive one because of the very low cathodic efficiency of deposited chromium as compared with nickel and also the extremely poor throwing power of chromium electrolytes. In parenthesis, it is curious to note that these two latter disadvantages of the chromium plating solution remain with the industry. Comparatively little progress has been made in these directions in the last 20 years. Nor does there seem at the moment any prospect of improvement in the near future. The production of a chromium plating solution of high efficiency and good throwing power would undoubtedly solve many very difficult problems with which the plater and chemist have to contend daily in the application of the process.



Courtesy of Carrier Engineering Co., Ltd.

Fig. 9.—Rotodip plant for the protective treatment of steel car bodies. The treatment consists in the application of phosphate coating followed by a primer.

Electrolytic Polishing

In the last decade, processes for polishing (or perhaps a better term would be "brightening"), metal surfaces have been developed to the point of commercial application. The pioneer work in this particular field was carried out by the French chemist Jacquet. The possibility of obviating the costly and time-consuming work entailed in producing polishes by mechanical means naturally caused considerable excitement when this new method of polishing was first mooted. Extravagant claims were undoubtedly made during the early period of development, and it is now apparent that electropolishing will not oust mechanical polishing for a long time to come, if indeed ever. Some of the difficulties arise from the fact that a fully highly reflecting finish can only be produced if the basis metal is reasonably smooth and free from superficial scratches, defects, etc., initially. Indeed, under certain conditions where deep scratches are present on the surface, these may be more noticeable rather than removed after electropolishing. The somewhat critical conditions of temperature, current density, etc., which have to be employed, the necessity for fairly frequent replacement of electrolytes and the cost thereof, together with the somewhat high currents which are necessary, are other adverse factors. Electropolishing, thus far, has proved to be

most applicable on such basis metals as stainless steel, aluminium and brass. It may be used effectively in producing a sufficiently high polish on cheap components, e.g., brass costume jewellery, knick-knacks, etc. Its other important application is in the engineering industries, where it has proved to be a valuable means of producing superfinishes and it has also been employed as an inspection tool, enabling the rapid assessment of surface defects on alloy steels.

Conclusion

It will be seen from the above, necessarily sketchy view that in the time that it has taken METALLURGIA to achieve its majority, big advances have occurred in the metal finishing industry. The industry is served by keen and enthusiastic workers both in the factories and in the laboratories, and many developments which are now impending are likely to prove to be of great value in the immediate future.

Twenty-One Years of Iron Foundry Progress

By J. Blakiston, M.I.Mech.E.

The general trend in iron foundries during the period under review has been the growing appreciation of mechanisation as a major contribution to increased productivity. Despite high capital and labour costs many modern mechanised foundries have been able to make substantial reductions in production costs ; an achievement which has involved much co-operation and adaptability from foundry operatives.

THE end of the 20's presented a problem which appeared to be unsurmountable to those who had been associated with the iron founding industry all their lives. The country had just emerged from one of the worst world trade depressions in history, which had witnessed the closing down of well-established foundries whose names had formerly been associated with the permanent stability of British industry. At that same time the iron founding industry, as a result of technical developments accelerated by World War No. 1, was assailed with extreme forms of competition from the new light alloy industry and other forms of metal fabrication, which were rapidly invading the field of what had been regarded as solely the perquisite of the iron founding industry.

At the same time there was emerging, although not so apparent, a complete change in engineering design conception. The slow moving, heavy reciprocating steam engine, with its attendant massive castings, was being slowly supplanted in most spheres by the internal combustion engine and electrical power, demanding castings of an entirely different design and specification from those formerly in vogue.

During the years of depression, large numbers of highly skilled craftsmen were forced out of the industry, and the recruitment of apprenticed personnel, designed to take their place in industry in the years to come, almost ceased and is still a problem. Fortunately there was still a number of far-sighted business men, executives and craftsmen, who retained their faith in the industry, and a glance through the proceedings of the Institute of British Foundrymen about that time, will reveal papers and reports which, although when written were regarded as far removed from the practical aspects of iron founding, have now become the established practice, carried out and understood by the smallest founders. Fortunately, many of those pioneers of production methods, sand testing and controlled iron specifications, are still with us, contributing their effort to the common good.

As economic conditions stabilised, the industry had to re-orientate itself to the new market demands, the customer now becoming insistent on the receipt of castings to specified tolerances, finish and material specification, the jobbing casting generally becoming much more intricate with lighter metal section, while the repetition section of the industry called for vast numbers of intricate cored, thin-walled castings, for the automobile and similar light engineering industries which, apart from the material specifications, demanded a constant flow of numbers to a planned schedule at extremely competitive prices.

The industry was fortunate in some respects in having a legacy of substantial buildings which, in many cases, could be re-modelled to cater for the new conditions. These buildings in some instances were over 70 years old, but, when modernised, compare very favourably with present day conceptions.

A brief study of building costs reveals wide inconsistencies. Comparing the cost of a jobbing foundry building with average characteristics, of sufficient area to undertake 100 tons of castings per week, the average prices of buildings, foundations, site preparation, vary as follows during the period under consideration.

1914. NEW
£25,000 .. .. 10s. per sq. ft.
1920. NEW
£50,000 .. .. £1 per sq. ft.
1930. NEW
£35,000 .. .. 14s. per sq. ft.
1930. OLD EMPTY BUILDINGS AVAILABLE.
£10,000 .. .. 4s. per sq. ft.
1950. NEW
£100,000 .. .. £2 10s. per sq. ft. and development charges.

From the above figures it will be noted that any firms who acquired good second-hand industrial buildings, about the 1929 period, placed themselves in a particularly advantageous position.

The rise in building costs over the last 21 years has also been accompanied by Factory Act legislation requiring certain amenities for the workers. This legislation, which was long overdue, has been carried a step further by the publication of what is known as the "Garrett Report," which gives concrete recommendations for further improving conditions in iron foundries. These amenities for the workers which include changing, washing and canteen facilities, can, in some cases, amount to as much as £100 per employee. It will be seen from this that it has been impossible for the more

recently erected foundries to compete commercially with the foundries which were acquired during the periods of low building costs without resort to mechanical aids to reduce the cost of production per head or per square foot of floor area.

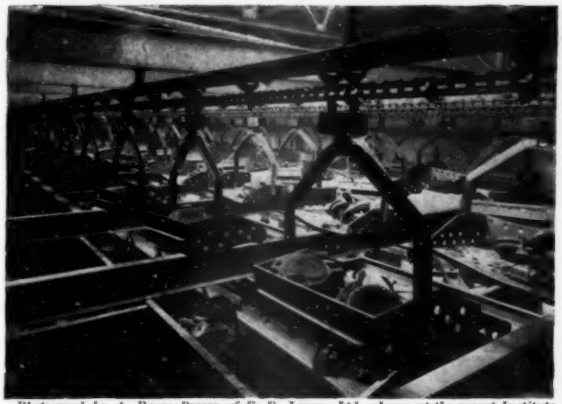
So, we witness to-day, a transitional period when old foundries, with antiquated methods of production, are just competing with the more recently constructed modern foundries with mechanised aids, with the advantage gradually passing to the latter as the personnel realise that they can earn similar or higher wages with less manual effort and under better working conditions, as is being brought about by the present day foundry conception of operation.

The building costs just described only represent a portion of the increasing capital necessary for the successful production of castings, and a corresponding advance has taken place during the last 21 years in the cost of the capital equipment required for casting production. The cranes, melting plant, sand mills, etc., for the typical jobbing foundry of 100 tons per week, costing 21 years ago approximately £10,000, have slowly risen to-day to somewhere in the region of £30,000, but this increase is only on the original plant conception which would to-day be inadequate to cater for the mechanical aids required for modern production methods. The probable cost of the mechanical equipment for a present-day jobbing foundry of the size being discussed, would be in the region of £50,000. In the same way the complete mechanisation to produce a similar tonnage of repetition castings would be in the region of £100,000. It will be seen from the above figures that the cost of equipping a foundry to meet present-day conditions, apart from those occasioned by rising prices, is steadily increasing, and on top of this the remuneration of the operators, coupled with their scarcity, to-day justifies a capital expenditure of £1,500 per head displaced. This figure, compared with the figure of £350 in 1929, which at that date would have been hard to justify, itself indicates the terrific changes which must have taken place in the conception of a mechanised foundry. The period in question has also witnessed a steady increase in casting prices, particularly in the case of castings not usually associated with fully mechanised production. A comparison between 1929 and 1950 is given below.

	1929	1950
Railway Chairs	£5 per ton	£18 per ton
Ships' Deck Castings	£9 per ton	£36 per ton
Machine Tool Castings	£14 per ton	£60 per ton

Compared with the above rising average prices, it can be stated that many of the modern mechanised foundries, in spite of the increased capital and labour costs, have been able to reduce the production costs on high duty intricate cored repetition castings, to, in some cases, as low a figure as £26 per ton, and this over the period in question represents a terrific achievement and augers well for the future of British industry as, apart from the technical aspects, this achievement has required a considerable amount of adaptability and co-operation from the foundry operatives.

Although many ingenious foundry devices and mechanical aids were developed towards the end of the last century, the general application of many of these proved methods, until quite recently, was the exception rather than the rule in the U.K., but with the force of circumstances, already described, it came to be generally realised that more efficient methods for handling foundry materials were becoming increasingly necessary.



Photograph by A. Royce Brown of F. R. Logan, Ltd., shown at the recent Institute of British Photographers Exhibition.

Conveyers operating in a section of a high production foundry.

A closer study has been made of materials flow to avoid repeated handlings and the metal stockyard was one of the first sections to receive serious attention. In the early days a certain amount of metallurgical prejudice existed against the mechanical charging of cupolas, but experience has proved the original fears to be unfounded and there are now very few foundry districts that cannot show many examples of efficient stockyard handling and cupola charging, emphasis being placed on skip charging for the smaller units, while drop bottom bucket charging is resorted to for the larger installations.

Similar attention has been paid to slag disposal, the results of which, in many cases, have transformed the cupola operational area into one of the cleaner sections of the foundry.

The use of motor and electric trucks for internal transport has gradually spread to many of the more progressive foundries. The use of this type of material handling in turn has demanded an entirely different conception of foundry floor layout, in some cases abolishing the sand floor entirely and in others dictating clearly defined pathways throughout the foundry. At the other end of the scale the more simple type of handling gear, which includes hand-operated chain blocks, portable lengths of roller conveyor and similar facilities, have now become a necessity to the moulder on account of the absence of a plentiful supply of unskilled labour, which was formerly always available.

Some of the earlier mechanised schemes were marred by the fact that it had not become fully realised that when mechanisation is considered, the moulding, machines, which can be called static mechanisation, only contribute approximately 25% to the final conception, the most important contribution being the fluid or handling mechanisation. The latter is developed along two principal lines, firstly, the mechanisation to bring the sand to the machines from the preparation plant, returning the used sand for re-conditioning after the casting operation has taken place ; the second form of development which has taken place much later is the realisation that the quick movement of the completed moulds from the machines, together with easy loading and unloading of the box parts, is one of the greatest contributory factors to high machine output. As the result of this, some of the more recently mechanised plants operating a reduced number of machines, are producing phenomenal outputs, in some instances

maintaining a continuous cycle of 20 box parts per hour from one machine, in the case of boxes 6 ft. × 4 ft., up to a continuous output, which has been actually recorded, of 300 box parts per hour in the case of a machine producing boxes 18 in. × 16 in. The above outputs do not represent abnormal manual efforts but are the outcome of planned facilities and the full utilisation of mechanical aids, many of which are of an extremely simple nature.

There have been very few developments or innovations affecting moulding machine principles, the jolting, squeezing and slinging methods with various modifications still being the accepted systems, but the sand slinger has become more universally acknowledged. This has probably been brought about by the more general adoption of sand systems which enable the slinger to work to a high degree of efficiency on both jobbing and repetition work. The foundry executive, learning by experience, has begun to associate the different moulding machine principles with certain classes of work and has become extremely competent and versatile in their operation, also he has lost his prejudice which was, in many cases, created by the expectation that one design of machine could be expected to cater for any type of work which happened to be available.

Apart from the production aspects of machine moulding, the stringent present-day demands from customers for accurate casting size has forced the hand of many ironfounders as the use of a moulding machine to produce an accurate casting is the only method open to him if he wishes to remain in business.

With the increasing demand for intricate cored castings, as previously remarked upon, the core shop in many foundries has now outgrown the moulding section and managements were quick to realise the same mechanical handling and production facilities, as used in the moulding shop, could readily be applied to core making. The use of female labour in this department, even discounting the influx during the war years, is becoming more marked, and again in this section of the foundry, although they have been proved for more than half a century, the core blowing machine is coming into universal popular use, this method of operation being particularly suitable for the female employee.

Parallel to the moulding and core shop developments the stove and drying facilities, on account of fuel conservation and fume prevention, have attracted a considerable amount of research work, and, generally, it can be stated that the foundry operator, at all levels, is becoming increasingly reliant on instrument readings instead of his sense of touch and sight, which can be particularly jaundiced on Monday morning.

The general acceptance of sand testing and control methods has led to the use of synthetic sands and other variations including cement bonding. The responsibility for producing a satisfactory sand to maintain the best casting finish has gradually been transferred from the moulder to the foundry technical control. Although sand control methods have opened up these new fields, the older moulding sands consisting of natural bonded green sand, dry sand and loam, are still very much in vogue and are never likely to be entirely displaced. Time has proved that foundry technical developments operate most efficiently when used to reinforce the traditional methods of moulding rather than when they are used to displace the older methods entirely.

A further advance of mould development has been brought about by the adoption of permanent metal moulds, which has met with a degree of success in a limited field. This system again is only another case of the development of an old moulding system helped by technical and metallurgical research.

The final dressing and inspection of the castings is now receiving considerably more attention than hitherto. Mechanical aids are now universally used by the dressers, and, with the customer expecting a high degree of finish on his casting, shot blasting has become practically universal, except in the case of the cheaper castings. A considerable amount of development work has taken place along this line by the introduction of water pressure cleaning for the removal of core masses and by using mechanical methods of propelling the shot, a system which, in many cases, is more economical than the pneumatic methods, although each method named has its own particular field.

It has become generally realised that it is in the foundries' own interests of economy and reputation that a system of internal inspection should be maintained. This system, commencing with the laboratory control of raw materials, in many cases extends to core jigging and casting waster analysis, and is the basis of some of the proprietary control systems which have come into vogue. The final inspection is followed, in some cases, by a prime painting operation as one of the present-day machine shop trends is to demand a cleanliness of operation which precludes the acceptance of dirty and rusty castings.

The present trends of foundry development as enumerated are likely to continue in a more intensified form in the future, because of the increasing costs of buildings, plant and rising wages, and it is obvious that more production must be resorted to if industry is to survive. Although the foundry operator is exhorted both politically and by the management to give a greater effort, it is obvious to those familiar with intensive foundry production that this section of the industry can do little more manually than is being done. Steps should be taken, however, to obtain a more intensive production per square foot of floor area and per unit of capital expended by a much more open approach to the fluid aspects of foundry mechanisation, even when applied to jobbing work. It does not need a time study to reveal that in the average foundry most of the units are only working to a fraction of their capacity either on account of the plant being unbalanced or the absence of the little facilities which enable the operator to achieve high outputs with a minimum effort.

In the older foundries there is still a certain amount of prejudice which would occur under similar circumstances anywhere in the world, which requires tact and a personal approach to overcome. The presence of this factor places a concern starting *de nouveau* in a very strong position in spite of the teething troubles generally experienced.

The following up of the trends described is of extreme importance to the U.K. as many European countries which formerly held an agrarian population are becoming extremely industrial minded. In addition to this, some of the so-called backward nations in the Middle and Far East are becoming nationalistic and industrially self-contained, and from the writer's personal observations many of the large foundry projects, which have recently come into operation, are being manned with an enthusiasm and an adaptability which should bring home to every person in the U.K. the importance of keeping pace with industrial production progress.

Progress in Welding 1929-1950

By A. J. Hipperson, B.Sc.(Eng.) and R. G. Burt, O.B.E., B.Sc.(Eng.)

Liasion and Development Department, British Welding Research Association

During the past 21 years, welding has assumed a rapidly increasing importance as a fabricating process; in many cases it offers a distinctive advantage over other methods of production, while in an increasing number of cases it offers the only practicable solution. Its wider and more general use has necessitated developments in equipment and appliances and in welding techniques, and the authors direct attention to the main contributing factors to progress in the welding fields.

DURING the period under review welding has assumed a rapidly increasing importance as a fabricating process and developments in welding equipment and appliances and in welding technique have, of necessity, had to try and keep pace with the large and rapidly increasing range of new and improved materials produced by metallurgical research and development.

The increasing importance of welding as a fabricating process is attributable to several factors of which the following are worthy of note. In many cases the change to welding as a fabricating process is being brought about by force of circumstances due to the unpopularity and decline of certain trades such as riveting. In other cases welding offers distinct advantages over other methods of production in such matters as economy in and more effective disposition and use of material, quicker development of prototypes and getting into production of new designs, speedier production, etc. The most important factor is, however, the increasing number of cases in which welding offers the only practicable solution. It may truly be said that welding has made possible several important engineering developments, such as larger boiler drums for higher pressures and temperatures, the large pressure vessels used in the oil refining and chemical industries and the development and production of the gas turbine and jet propulsion engines.

Metal Arc Welding

At the beginning of the period under review the covered or coated type of electrode for metal arc welding was well established and progress in this field since 1929 has been mainly in the direction of developing new and improved types of electrodes and automatic and semi-automatic welding machines. Developments in electrodes have enabled better quality welds to be produced, broadened welding techniques (for example, by the introduction of " Deep Penetration," " Deep Groove " and " Contact " types of electrodes) and have enabled welding to be applied to a rapidly increasing range of materials of which particular mention may be made of medium carbon steels, alloy steels including armour plate and the corrosion resisting and heat resisting steels, high tensile structural steels, aluminium and the light alloys. An interesting recent development in metal arc welding is the introduction of the " Twin Electrode " which has two core wires enclosed in a common coating and which is operated on 3-phase supply.

Considerable attention has been devoted to the development of automatic and semi-automatic welding machines and appliances, the object being not only to increase production, but also to produce welds of more consistent quality by stabilising welding conditions and reducing or eliminating the variable human element ever present in manual arc welding. The " Submerged Arc " process, in which the electrode is in the form of a coil of bare wire and the flux fed as a powder under which the arc is submerged, originated in the U.S.A. and was patented in 1934, though it is claimed that the process was used in Russia at an earlier date. Though mainly developed as a fully automatic process, there are also developments in which the electrode is manipulated manually. Development of automatic metal arc welding machines in this country have been so far of types using the covered electrode in coil form consisting of a main core wire surrounded by helical wires, the interstices being filled with the flux. A recent development in Sweden is an automatic welding machine which, it is claimed, will take any standard electrode such as is used in manual arc welding and is, therefore, capable of a wide range of application.

Of the many interesting developments in the application of metal arc welding during the period 1929–50 special mention may be made of the following. Although the first ship to have welding applied in its construction on any scale was S.S. *Fulagar*, launched by Cammell Lairds as early as 1920, the first sea-going vessel specifically designed for welding was the S.S. *Peter G. Campbell*, built and launched by Swan Hunter Ltd. in 1934. This latter company also produced the first pre-fabricated ship which was the oil tanker *Noira*. The first all-welded war vessel was H.M.S. *Seagull* launched in 1937. During World War II there was considerable development in the welded fabrication of ships, both in this country and in the U.S.A. and this was a most important factor in the provision of an adequate number of ships for the maintenance of supplies. Underwater welding was first reported to have been carried out by Henroff and Levishitz in 1932, but it is now known that the Admiralty carried out tests of underwater metal arc welding as early as 1918. Developments in this technique have valuable applications in the repair and salvage of ships and other marine work.

Progress in welding technique has contributed largely to the marked developments which have taken place in the manufacture of pressure vessels, not only boilers, but also large and intricate vessels for the oil refining, chemical, brewing, dairying and food industries. These fabrications are carried out in a wide range of materials including corrosion and heat resisting steels and alloys, stainless clad and nickel clad steels, aluminium and light alloys.

Atomic Hydrogen Welding

Although the atomic hydrogen process was founded in 1926 on the work of Dr. Irvin Langmuir, there was

marked progress in the development and application of the process during the period under review. Langmuir found that by passing a stream of hydrogen gas through an arc, dissociation of the atoms of the gas took place and, when the atoms re-associated outside the arc, temperatures far higher than can be produced by any other gas welding process were achieved. In addition to producing the welding heat, the hydrogen gas also forms a protective shield around the molten pool of metal. The process has valuable applications and lends itself to arrangements for automatic operation.

Inert Gas Shielded Welding

Although the principles of inert gas shielded welding were patented in the late 1920's it was not until the period of World War II that the process was developed and applied on an industrial scale. In America the inert gas used is mainly helium though argon is also used and in this country argon only is used. Arising from this, the process is also known more commonly in this country as the argon arc process. The arc is struck between a tungsten electrode and the work in an atmosphere of inert gas which is usually supplied through a hood surrounding the electrode and which prevents oxidation. A filler rod is fed in separately as may be required. In certain types of joint the use of filler rod may be dispensed with. The process has been found very satisfactory for the welding of corrosion resisting and heat resisting steels and aluminium and light alloys. The application of welding to the light alloys in particular has been greatly facilitated and improved by the introduction of the inert gas shielded welding process and there are prospects of still further developments in this field.

In the U.S.A. there has been a further development of the inert gas shielded process which has so far not been established in this country. This is the " Aircomatic " automatic process. In this process the electrode, instead of being of tungsten and more or less non-consumable, is a bare metal wire of suitable composition in coil form which is fed automatically and also provides the filler metal.

Thermit Welding

Although the discovery of the thermit process dates back as far as 1895–1896, during the last 21 years there have been improvements in the process and developments in its application. The greatest use of the process for welding is in the joining of heavy sections and in this connection it has many valuable applications in the repair of heavy castings, machine frames, shafts, etc. Its use is by no means restricted to repair work, but extends to original construction and fabrication work, e.g., the joining of rails into long continuous lengths of track and, a more recent application, fabrication of very heavy components such as a ship's stern frame by welding together sections which may be large steel castings or forgings.

Pressure Butt Welding

By this process which is better known in America but is now being developed in this country, the butting faces to be joined, after accurate preparation, are brought together under carefully controlled conditions of temperature and pressure. The heat is applied externally by means such as a ring of oxy-acetylene, oxy-propane or similar flames, but electric induction heating is also being used and developed for this purpose.

Ancillary Processes

Of all the processes ancillary to welding, flame cutting is probably the most important. Considerable development of the process has been made during the last 21 years, and of progress and improvements achieved, special mention may be made of: economy of gas consumption, cleaner edges of the cut, more accurate cutting, various types of automatic profile cutting machines, multi-head cutters enabling preparations such as a double Vee butt weld edge preparation to be cut accurately with a single pass and " Powder Cutting " for flame cutting stainless steels and other metals which are not readily oxidisable.

Cold Welding

One of the major difficulties involved in the making of lap joints by resistance welding in aluminium sheet is the high electrical power required, and many would-be users of aluminium sheet as an alternative to mild steel have found considerable expense facing them in connection with the purchase of the required equipment. Various attempts have been made to find a low-power method for making welds in aluminium, one of the most notable of which is the cold welding process, which was developed in its present form soon after the second World War. It is in essence a scientific development of hammer welding, and involves the application of a force which produces a high intensity of pressure where the weld is required—a force sufficiently high in fact to produce considerable deformation. No heat whatever is applied, but to secure a sound weld, the surfaces of the sheet must be free from oxide. This process has a field of application where lap joints are required, and where considerable thinning at the weld, of the order of 70% of the thickness of the sheet, can be tolerated.

Resistance Welding

The use of resistance welding has increased more than ten-fold during the past 21 years, the greatest rate of increase being coincident with the years of the second World War. The reason for this was the particular suitability of resistance welding to the needs of mass production. To-day, resistance welding is used in the mass production of such engineering assemblies as automobiles, gas turbines, aircraft components, office furniture and the like.

Twenty years ago, resistance welding was almost entirely dependent upon the skill of the operator, whose job it was to apply pressure manually and to judge the duration of welding current. As a result, inconsistencies were frequently obtained which were difficult to detect without destructive testing. With the advent of electronic controls, and notably ignitron and thyratron tubes, completely automatic machines were developed which, in operation, were independent of the operator after depression of a switch. Fully automatic machines are capable of welding at a rate of 100 welds per minute or more, and the cost of making 100 welds on such machines is only a few pence, including depreciation, operators' time and all overheads.

Notable recent developments in resistance welding are the multi-point machines, and the three-to-one phase conversion system. The multi-point, or hydromatic machine, is a special purpose machine which automatically carries out a pre-set sequence of spot

welding after the components have been loaded into it, and such machines sometimes have 200 pairs of electrodes, all independently operated. This process is well established in the automobile industry in America, and is gaining popularity in this country. The three-to-one phase conversion system greatly alleviates power supply problems, in that it uses electricity from all three phases at a power factor closely approaching unity. The principle of operation of the conversion system is first to rectify the incoming A.C. from a three-phase transformer by means of ignitrons, and the D.C. so formed is passed to the primary of a special welding transformer. As the core reaches saturation point, the D.C. is switched off by further ignitrons until the current dies down to zero ; the D.C. is then applied to the primary in the reverse direction, and so on, resulting in a low frequency alternating welding current.

Welding Research

Inevitably, the rapid growth which welding has undergone during the last twenty years has introduced many new engineering and metallurgical problems. More than thirty different welding processes are being used in industry to-day, each one of which has a field of application to which it is best suited, and each one carries with it its own problems. In order that these increasing problems might be dealt with, a central body specialising in welding research was set up in 1936 in the Institute of Welding following an International Welding Convention. This research orgnisation was later established on an independent basis and became the British Welding Research Association, incorporated in the scheme which the Department of Scientific and Industrial Research provides for Research Associations. Its income grew from less than ten thousand pounds in 1937 to over seventy thousand pounds for the year 1949–50. The Association's research on welding embraces all fields of engineering, including work on structures, fatigue, high tensile steel, pressure vessels, and resistance welding. From this work, together with that in hand at Universities and in the laboratories of industrial organisations, are emerging codes of practice and recommendations on welding techniques which go far toward establishing welding as a most important assembly process of the present day, and the most promising one of the future.

Developments in Laboratory Methods and Apparatus

H. J. Axon, D.Phil. and K.M. Entwistle, Ph.D., M.Sc.

A large number of new tools and techniques have been made available for the laboratory examination of metals and alloys during the past 21 years which have greatly assisted investigations and the solution of metallurgical problems and thus added to the store of knowledge. Many of these are included in the present review.

IN the twenty-one years under review a large number of new tools and techniques has been made available for the laboratory examination of metals and alloys. In the field of microscopic metallography alone, this period has seen the widespread use of both thermosetting and cold setting plastics for mounting small metallurgical specimens and the introduction of taper sectioning for the study of surface structures. Electrolytic polishing has become available as an alternative to mechanical polishing in cases where a particularly strain free surface is required or for routine examination of a series of similar alloys. As a consequence a fresh interest has been developed in the technique of electrolytic etching. Polarised light has been applied to the study of slag particles, intermetallic compounds and, more outstandingly, to the investigation of thin surface films, whilst more recently the completely new development of phase-contrast microscopy and the construction of the reflecting microscope has given a new impetus to microscopic metallography. It is expected that these two tools will be widely used in the near future. The reflecting microscope with its long working distance should facilitate the examination of hot specimens, a subject in which interest has been revived on account of thermal etching effects.

The main developments in the last twenty-one years, however, have been associated with the exploitation of electrical energy in metallurgy. Laboratory furnaces of the electrical resistance type are widely used for annealing experiments up to 1,600° C. and correspondingly a great development has taken place in the construction of temperature regulators and recorders. Temperature recorders are still usually of the mechanical type actuated by a chopper-bar mechanism but an extensive range of potentiometric-mechanical and purely electronic bridge circuits have been developed for accurate control of temperatures, whilst the bi-metallic strip energy regulators give satisfactory temperature control where high accuracy is not required. The increasing demands by both research workers and industry for more reliable temperature measuring instruments have stimulated significant developments in this field since 1929. The most notable has been the introduction of pyrometers using barrier-layer photocells ; their attractive feature is the short time lag which allows more rapid temperature variations, for example during induction heating, to be followed accurately. In these pyrometers the radiation falling on the cell is usually chopped by a rotating toothed wheel so that the cell output voltage can be amplified by conventional circuits and D.C. amplifiers are unnecessary. It is now possible to measure source temperatures of the order of 100° C. by the radiation emitted, using the lead-sulphide photo-cell which has a sensitivity peak in the infra-red. Other innovations in pyrometry include the development of a D.C. amplifier and recorder with rapid response suitable for use with a thermo-couple for recording rapid cooling, for example during quenching. Improvements have been made to the design of optical pyrometers, particularly in lamp filament design and details of the optical system. It is

claimed that the use of polarised light in disappearing filament pyrometers ensures complete "disappearance."

Small induction heating furnaces of the valve oscillator type have developed from a laboratory curiosity into an essential tool for the study of the more refractory metals, whilst the ultra refractory metals are now being studied by the methods of powder metallurgy. The study of the ultra refractory metals is made difficult on account of the tendency of the metals to oxidise and to react chemically with most of the available refractory materials. In this respect the development of reliable vacuum techniques has proved invaluable, together with the arc furnace which, when constructed with a water-cooled copper hearth, allows melting to be carried out without contact with ceramic refractories.

X-Ray methods were certainly available twenty-one years ago, but in the ensuing period these methods have been extended greatly and X-ray examination has come to provide a routine control in many laboratories.

The technique of radiography, using high voltage tubes or radio-active sources, has become well established in industry and the allied technique of microradiography is coming to be accepted in the laboratory.

More spectacular progress has been made with X-ray crystallography. The X-ray tube which is most widely used in metallurgical laboratories is the demountable continuously evacuated type, but a recent and important development is the rotating target X-ray tube, from which a more intense X-ray beam may be obtained. This is important in relation to the growing use of crystal monochromators for the production of truly monochromatic X-ray beams and the general trend in favour of large diameter X-ray cameras. Increased camera size leads to increased resolution of diffraction lines and the period under review has seen the size of cylindrical Debye-Scherrer cameras grow from a diameter of 5 cm. through 9 cm. to 19 cm. and occasionally larger. A great deal of attention has been paid to the sources of error which may arise in X-ray crystallography and the present technique is to remove or minimise instrumental errors and to make corrections for the effect of absorption of X-rays in the specimen. Parallel to the development of accurate and reliable cameras for work at room temperature there has been the development of cameras capable of taking photographs of specimens at low or at high temperatures. Low temperature X-ray techniques have not been used extensively in metallurgy so far, but a large number of high temperature cameras have been constructed. It is important in such instruments to prevent oxidation of the specimen and also to know the temperature of the specimen accurately. These ideals have been achieved in various degrees by several methods: by enclosing the specimen within thin silica tubes, by completely evacuating the camera, or by various designs of furnace and thermocouple arrangement. It is expected that high temperature X-ray methods will develop considerably in the future in association with the investigation of high melting point alloys. Apart from the measurement of lattice spacings and the elucidation of crystal structures, the X-ray method has provided a useful additional tool for the determination of phase diagrams; whilst considerable discussion has taken place over the relative merits of X-ray and classical methods for this purpose, it is now generally recognized that the two approaches are complementary. X-ray methods have also been developed for the determination of crystal size and orientation and of stress in mechanically worked materials. The greater triumphs of the X-ray methods have come from the study of precipitation and pre-precipitation phenomena and of superlattice formation, two effects which do not yield so readily to study by classical methods. It is important to mention the development of apparatus for determining specific heats accurately over a range of temperatures which, in conjunction with the X-ray method, has given valuable information about formation of superlattices and ordered structures in alloys.

The technique of electron diffraction has been developed along with X-ray methods. The fundamental principles of the two methods are identical but the penetrating power of X-rays has been used to obtain information about the interior of solid alloys whilst the electron diffraction method has relied on the much smaller penetrating power of an electron beam to obtain information about very thin films, by transmission methods, and about surface structures by reflection methods. The two techniques taken together can thus provide a range of information about surface and bulk properties. One outstanding aspect of electron diffraction methods is the use of a completely evacuated camera, in which it is possible to prepare a fresh surface by evaporation and condensation, and to examine the freshly deposited surface by electron diffraction without breaking the vacuum. High temperature cameras have been constructed in which the specimen may be heated to any desired temperature and examined at that temperature. The method has led to a great increase in our knowledge of surface structures, oxidised and tarnished films, the Beilby layer and the nature of electrodeposited and other coatings.

The diffraction of electrons was demonstrated experimentally rather more than twenty-one years ago, but the development of electron microscopy, which is also based upon the wave nature of the electron, has certainly taken place within the period under review. Various types of electron microscope exist, among which are instruments in which the specimen forms the cathode from which electrons are emitted and focused by an electromagnetic lens system; alternatively auto-electronic emission from the cathode is made to produce an enlarged image, by virtue of the geometry of the instrument, without focusing lenses. The instrument which is likely to prove of most importance, however, is the transmission type high resolution instrument. This instrument has been used to produce magnified images of very thin metal films condensed on to a collodion base but, as in the electron diffraction method, the electron beam is not capable of penetrating an appreciable thickness of metal, and the transmission electron microscope is used chiefly to extend the range of surface structures which can be studied by ordinary light microscopy. The technique depends upon the production of a replica of the surface which is to be studied, the replica must be transparent to the electron beam and stable in the beam, it must moreover possess sufficient contrast to produce a clear image and must bear some known and preferably exact relationship to the actual metal surface. The conventional methods of polishing and etching thus play a part in electron microscopy although the methods of electropolishing and electrolytic etching have been widely used. Early methods of preparing replicas depended upon the production of layers of organic material which were cast on the etched

surface and took up a negative impression of the surface. The replica layers were then stripped from the surface mechanically and examined. Later developments of replica producing technique have included the deposition of evaporated silica on plastic replicas, the shadowing of replicas to produce increased contrast and the use of oxide films stripped from the metal surface. Such oxide film replicas have been made by direct oxidation of the metal and also by the special technique of anodic oxidation of aluminium. This latter method is applicable to the study of material other than aluminium alloys, since a block of pure aluminium may be pressed on any hard surface which it is wished to study; the aluminium takes up an impression of the original surface which is then anodically oxidised and stripped for use as a replica.

Much development work has been done on the instrument itself and it is now possible to buy commercial machines which incorporate both electron diffraction and electron microscope outfits. Similarly the various replica techiques have been critically studied and delight at the essential novelty of the method has given way to the realization that electron microscopy must be used in conjunction with, rather than in competition to, the available methods of light microscopy.

The technique of spectrography as related to chemical analysis has been in use for a considerable time as a research tool, but the period under review has seen the technique develop in power and become the basis of routine testing in industrial control laboratories. This change has come about as a result of the careful attention to, and strict standardization of, all stages in the application of the method. Spectrographic methods have been used extensively in the study of diffusion processes, a field of study which has been altered completely in the period under review by the realisation that diffusion coefficients may vary with the concentration of the diffusing material.

Radioactive isotopes have been used in the study of self-diffusion processes and attempts have been made to measure the diffusion rates of stable metallic isotopes by methods involving the mass spectrograph.

Radio isotopes have also been used in the study of surface reactions and friction properties and the extension of isotope methods is to be expected in the future for studies of diffusion, metal or gas flow, oxidation and segregation. A limitation in this work may be the availability of a radio-active isotope of the element required with a convenient half-life. The measurements which are made involve the determination of the intensity of radiation—generally a mixture of beta- and gamma-rays—using Geiger-Müller counters; in some cases the beta radiation is filtered by lead screens. An example of a recent metallurgical application of the radio-active tracer method is the investigation of the role of sodium in the modification of aluminium-silicon alloys.

A further technique of very recent origin and associated with the development of radio isotopes is the method of neutron diffraction. The scattering power of atoms is often quite different towards X-rays and towards neutrons and it is anticipated that the new, and at present expensive, method may supplement the information available from X-ray diffraction in alloys containing light atoms such as carbon or nitrogen, and in systems involving two atoms with similar scattering powers towards X-rays.

In the field of mechanical testing, the last twenty-one years have seen the introduction of fatigue testers using a simple form of bar specimen, either freely supported or clamped as a cantilever, and maintained in vibration at one of its natural frequencies by some form of electronic feed-back circuit. The increased frequency of vibration, compared, for example, with the rotating beam test, results in a reduction of the duration of the test. Further, it has been shown to be possible, by careful design of the apparatus, to measure the energy dissipated in the specimen during vibration, and from this the energy accumulated as internal strains; this information is likely to throw valuable light on the mechanism of fatigue.

Considerable effort has been directed in recent years to the extension of diamond indentation tests down to applied loads in the range 1 to 100 grammes. Under these conditions the impression is very small and therefore more reliable hardness values may be obtained for thin strip and individual constituents in a microstructure; in addition the technique is appropriate for the measurement of steep hardness gradients, for example across a nitrided layer. Much development work remains to be done on instruments designed for this purpose. It is now clear that attention must be directed towards such factors as surface preparation of the specimen, geometry of the indenter, extraneous vibration and inertia of moving parts and measurement of the impression. In metallographic work one troublesome uncertainty is the depth of the micro-constituent under the indenter.

The range of devices for the measurement of strain—both direct and alternating—in metals has been extended considerably. Strain gauges are now available utilising a variety of strain sensitive properties, for example the electrical resistance of a wire bonded to the metal surface, the capacitance of a condenser, the inductance of a coil moving relative to a ferromagnetic core or the frequency of transverse vibration of a stretched wire fixed to the surface at two points. The brittle lacquer technique is useful in showing up highly stressed regions and indicates maximum tensile strains. The photo-elastic method has metallurgical applications in addition to the determination of stress distribution in both two- and three-dimensional models; for example in cold rolling research an elegant method for the measurement of the variation of normal pressure over the rolled stock has been developed in which the pressure is transmitted, by a pin in the roll face, to a block of glass; this develops birefringence under pressure causing a variation in the intensity of polarised light transmitted through it. Double refraction in massive polycrystalline silver chloride after deformation is of particular interest in the study of the deformation of metal polycrystals because of the metallic character of the former.

Another recently developed optical technique of value is that of multiple beam interferometry which is used for measuring the topography of surfaces. It has already been applied with success to the study of slip bands and the perimeter of hardness impressions.

Outstanding experimental developments in the study of the deformation properties of metals have centred on vibration behaviour. Precise measurements of elastic moduli have been made from the natural frequency of bars in different types of vibration. This method is of particular value in determining the dependence of

modulus on orientation in single crystals, since the operating stress can be made extremely low. For the same reason the technique is ideal at elevated temperatures. It is important to realise that the dynamic modulus given by vibration methods may be greater than the static value, but in many cases the difference between the two can be derived from theoretical considerations.

Elastic constants may also be measured from the velocity of an ultra-sonic pulse, a technique which also forms the basis of the ultra-sonic flaw detector in which cracks, flaws, imperfections and other discontinuities are located from the time taken to receive a reflection of a pulse from them. Other crack detectors developed recently include the magnetic type, which uses a colloidal suspension of a ferro-magnetic in paraffin, and the fluorescent liquid method.

Measurement of the dissipation of vibrational energy, or damping capacity, of metals has been the subject of detailed investigations in the last fifteen years. Experimental activity has been directed towards the development of reliable methods which measure energy dissipation arising only from effects within the specimen. It has been shown that, in order to establish this condition, such factors as gripping or suspension of the vibrating specimen, air friction, interference from the amplitude measuring device and aberrations in the measuring circuit require careful consideration. The damping values obtained under conditions of low external loss have been shown to be directly related to the structure and condition of the metal. Particularly valuable results have been obtained from tests at low stresses in which temperature, frequency or kind of vibration have been varied. Damping measurements have now become an indispensable tool in physical metallurgy research.

The damping capacity of metallic specimens is affected by the presence of cracks or flaws, and therefore may be used as the basis of a non-destructive test. Indeed several methods have been developed for specific applications, such as the detection of season cracks in brass cartridge cases, but any universal use of the methods seems unlikely at present since, firstly, cracks may be undetected if they are in a region of low vibrational stress, and, secondly, no simple technique appears possible for measurement on finished components of widely differing shape, size, material and frequency of vibration. The well-established methods, such as tapping railway wheels with a hammer, or dropping pennies in a sound-proof room, are not likely therefore to be superseded in the near future.

Two valuable experimental methods are now available for research in ferromagnetic materials. The torque magnetometer measures the nature and degree of anisotropy in ferromagnetic sheet from the variation of torque on a disc as it is rotated in a saturating magnetic field. The variation of saturation intensity of magnetisation with temperature can be followed with the magnetic traction balance, and has been applied in confirming equilibrium diagram determinations in, for example, the iron-nickel and iron-nickel-aluminium systems.

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21 Years of Progress in The Zinc Industry

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Above the heated portion of the retort is an unheated height of 12 ft. known as the 'eliminator'. This plays an important part in maintaining efficient condensation by permitting a certain amount of reversion and lowering of the carbon dioxide content of the vapours. The zinc oxide formed is deposited on the briquettes and carried down into the heated zone to be reduced again. The eliminator also serves to reduce the lead content of the vapour leaving the retort.

At the top of the eliminator the vapours pass into a 'down-comer' built of carborundum brick. This leads into the condenser sump which is rectangular in section 18 in. wide by 8 ft. long and 3 ft. high. Baffles are hung in the sump and 'down-comer' so as to obtain full utilisation of cooling surfaces. The metal is tapped from the sump and either cast into plates for sale or taken in its molten state to the refluxers for redistillation.

The Production of High Purity Zinc

In 1934 a unit capable of producing 8 tons per day of high-purity metal was installed at Avonmouth. Since that date progressively large units have been built, until the present refluxer is capable of producing 60 tons per day of Crown Special 99·99% zinc from vertical retort metal.

The refluxer relies upon the difference in boiling point between zinc and its impurities. Lead, tin and iron are less volatile, while cadmium has a higher vapour pressure. The principle employed is therefore, to subject the metal to be refined to a preliminary vaporisation, leaving the less volatile constituents in the run-off. The zinc vapour leaving the top of the first column, still containing all the cadmium initially present, is condensed, and then fed into a second column. Here, a proportion of the zinc containing the cadmium is re-evaporated and subjected to reflux condensation. Substantially all the cadmium is eliminated and high purity zinc withdrawn from the base of the column.

Zinc Alloys

With the commercial production of 99·99% purity zinc, the way was open for the development of applications of zinc die casting alloys. However, it was not until the beginning of the 1939 war, when the Government turned to the zinc pressure die casting industry for the production of many of the vast number of components required for the Services, that their many potentialities were realised since the requirements for the Services stores were often very exacting. Confidence in the industry was not misplaced, and a prodigious number of castings were produced, including vehicle parts, gun sights and components, radar equipment and a very large quantity of ammunition parts, many of them of an extremely complex nature. The manner in which these withstood the rough handling inseparable from war-time use, and their behaviour in all sorts of climatic conditions, have given peace-time users added confidence in zinc alloy die castings.

Under the stimulus of war, improved die casting machines and methods were introduced, which have increased the ability of zinc alloy die-casting to withstand shock loading and resulted in further application of these alloys to relatively highly stressed parts.

BS 1004, which limits the harmful impurities in zinc alloys and zinc alloy-castings was introduced in 1942

primarily to protect the production of Service stores. It performed a very useful function in this respect. With its wider acceptance for ordinary commercial use the danger of inter-crystalline corrosion as a consequence of contamination has been greatly reduced and applications of zinc alloy die-castings have been extended with confidence. Zinc alloy die castings conforming to BS 1004 have proved satisfactory in tropical conditions where Cronak treatment has been of value in alleviating superficial corrosion.

The motor industry was one of the first to utilise zinc alloy die casting on a large scale, and it is still probably the largest peace-time consumer. In the U.S.A. particularly large radiator grilles are a prominent feature of the latest designs. The complicated and distinctive shapes could not be achieved economically by any other method of manufacture, and their dimensional accuracy greatly simplifies assembly. In Great Britain, although these rather flamboyant designs are not popular, the simpler radiator grilles are also die cast in zinc alloy by several manufacturers.

Zinc Sheet

While zinc sheet has a large number of established uses, particularly in the manufacture of cans for dry batteries, mention should be made of its application in building. Zinc roofs are an important architectur a feature on the continent of Europe, but in this country the material has not received as much attention as it deserves. Zinc sheet is one of the lightest permanent roofing materials obtainable, Nos. 14–16 zinc gauge sheets (0·031–0·041 in. thick) being in common use. After short weathering it forms its own protective coating, and drippings do not discolour woodwork and masonry. It is likely that its popularity as a roofing material will increase. BS 1431 covering zinc rainwater goods was introduced in 1948.

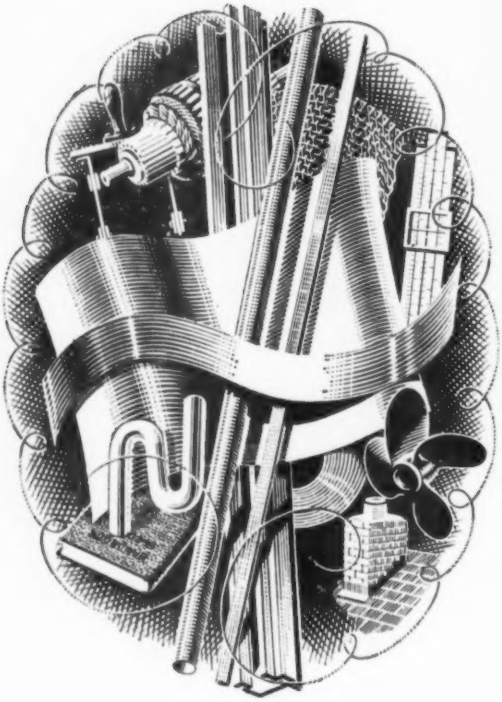
Zinc Coatings

The use of zinc coatings on iron and steel for their protection is well established. Recommended thicknesses of coating for specific purposes are put forward in PD 420, 1945 (Methods of protection of light gauge steel and wrought iron used in permanent building construction). The oldest coating method, hot dip galvanising, has returned to its peace-time importance.

Electrodeposited zinc coatings are extensively used. The application of the heavier coatings electrodeposited by the " Tainton " electrogalvanising process has now found a specialised field in the manufacture of wire ropes, the process bring used as an alternative to hot-dip galvanising. Electrogalvanising gives a ductile, adherent, high purity coating of uniform thickness and, since it is carried out at room temperature, does not influence the strength of the wire.

The value of zinc coatings has been recognised in B.S. 990 (1945) dealing with the construction ofmetal casement windows and doors, which states that these shall be protected by a zinc coating applied by galvanising, spraying or sherardising.

1 Of the three, spraying has certain advantages, particularly for protecting large structural steel work. Sprayed coatings provide a satisfactory base for paint. The wire fed to the spray pistol is made by extruding billets of 99·99% zinc into rod, which is finally drawn into wire ; the high purity of the zinc is an additional factor in protection against corrosion. Other spraying methods use zinc powder or molten metal.



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